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Development of a Human Performance Model of a UAV Sensor Operator: Lessons Learned

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NOTICES

TECHNICAL REVIEW AND APPROVAL

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

//Signed//

MARIS M. VIKMANIS
Chief, Warfighter Interface Division
Air Force Research Laboratory

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This report consists of five parts. Part one introduces the concepts of human-in-the-loop (HITL) virtual simulation, modeling and constructive simulation, and the human as an information processor. Part two introduces the constructive modeling tool used in the current study, the Combat Automation Requirements Testbed (CART), and briefly reviews two recent case studies where it was applied. Part three describes the effort to develop an in-house constructive simulation capability. Part four documents the development of a human performance model (HPM) for an Unmanned Aerial Vehicle (UAV) sensor operator (SO). HPM development activities included the creation of a mission scenario, identification of functions and tasks performed by a UAV SO on a typical mission, and model development (e.g., function and task decomposition, workload and response time estimation, and modeling). Part five summarizes lessons learned and proposes potential future activities.

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PREFACE

This report describes activities performed in support of the Air Force Research Laboratory Warfighter Interface Division, System Control Interfaces Branch (AFRL/HECI) Unmanned Air Vehicle Interface Defense Technology Objective (UAV DTO), Work Unit 71840972 (UAV Decision Support Interfaces).

The primary author, Mr. Michael Petkosek, was a graduate student employee of the Consortium of Research Fellows Program (CRFP) while the work described herein was performed. The CRFP is managed under the auspices of the Consortium of Universities of the Washington Metropolitan Area which, since its inception, has grown to include graduate and undergraduate students and faculty from 45 colleges and universities nationwide in a wide array of disciplines. In 2005, Mr. Petkosek successfully completed his graduate degree in Experimental / Human Factors Psychology at the University of Dayton. It was during the pursuit of his graduate degree that he also was employed by the CRFP in support of the Human Effectiveness (HE) Directorate at Wright Patterson AFB, OH. In June 2005, Mr. Petkosek became an associate research engineering psychologist for HE's Warfighter Interface Division, System Control Interfaces Branch. AFRL/HECI would like to thank the CRFP and the University of Dayton for the cooperation, support, and encouragement it received during Mr. Petkosek's fellowship.

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DEVELOPMENT OF A HUMAN PERFORMANCE MODEL OF A UAV SENSOR OPERATOR: LESSONS LEARNED

This report consists of five parts. Part one introduces the concepts of human-in-the-loop (HITL) virtual simulation, modeling and constructive simulation, and the human as an information processor. Part two introduces the constructive modeling tool used in the current study, the Combat Automation Requirements Testbed (CART), and briefly reviews two recent case studies where it was applied. Part three describes the effort to develop an in-house constructive simulation capability. Part four documents the development of a human performance model (HPM) for an Unmanned Aerial Vehicle (UAV) sensor operator (SO). HPM development activities included the creation of a mission scenario, identification of functions and tasks performed by a UAV SO on a typical mission, and model development (e.g., function and task decomposition, workload and response time estimation, and modeling). Part five summarizes lessons learned and proposes potential future activities.

INTRODUCTION

The traditional approach to assessing the impact of new systems or system enhancements on operator performance and mission effectiveness has been to conduct HITL virtual simulations. These can be both expensive and time consuming, requiring hardware and software development and subject-matter-experts (SMEs) to serve as test participants. Human performance models and constructive simulations have been proposed as alternatives to traditional HITL virtual simulations (Defense Modeling and Simulation Office, 1995; Pew & Mavor, 1998). Proponents suggest that HPMs and constructive simulations offer reduction in the cost of test and evaluation (e.g., analysis of requirements/alternatives, cost/benefit studies, design, training) and the ability to move test and evaluation activities earlier in the system design process. Further, modeling and simulation is critical to the acquisition of new systems in the current environment of limited resources, shrinking budgets, and legislated reform.

The stated objective of the Under Secretary of Defense for Acquisition and Technology for the military has been to "develop authoritative representations of individual human behavior" and to "develop authoritative representations of the behavior of groups and organizations" (Defense Modeling and Simulation Office, 1995). To address these objectives, AFRL/HECI created an in-house HPM and constructive simulation capability, the Organic Modeling Team (OMT). The team's first application was the development of an HPM of a UAV SO.

Modeling and Simulation

Simulation is the process of using an abstract model to gain a better understanding of a system (Micro Analysis & Design, 2003). An abstract model and the understanding that can be gained are two key components of building and using a simulation. A simulation is seen in the combination of a model and a scenario. This definition includes several important concepts. An *abstract model* refers to a manufactured version of something that is real. It is abstract in that it does not represent an entire system (or person). A *better understanding* means that the purpose of modeling and simulation is to gain insight about events and their consequences. This provides a practical means of system analysis. The *scenario* referred to is a software generation of a specific time period. It contains the hardware (systems), software (givens), liveware (people), and environment that the model encounters as the simulation is executed. The scenario can be likened to the mission level of decomposition. That is, Model + Scenario = Simulation.

The purpose of a simulation is to represent reality in a meaningful way. The simulation is executed by the model's movement through the scenario. A *constructive simulation* is created when a model runs in a software-based scenario. This has been identified as a substitute for human operators and HITL virtual simulation. Constructive simulation is more efficient than virtual simulation because less time is required to run a computer scenario. Further, because SMEs, extensive simulator equipment, and maintenance are not needed, the HPM is also more cost effective. These benefits allow for the ease of conducting and repeating simulations.

Dynamic system simulation is a form of simulation that projects a system's dynamic properties. There are two types of dynamic system simulation, continuous and discrete-event. This report focuses on efforts of discrete-event simulation.

Discrete-event simulation. Discrete-event simulation is used to represent processes that can be described with a network of events. The network is comprised of isolated operator tasks linked by pathways that indicate order of execution. A process that is represented with discrete-event simulation must have an identifiable beginning and end. Simulation is driven by movement through the network along the pathways. Discrete-event simulation typically is used to represent three distinct types of processes:

- Human operation of a system (e.g., a pilot's actions through a section of flight)
- Manufacturing processes (e.g., an assembly line)
- Queuing processes (e.g., customers being served by tellers)

Discrete-event simulation is defined by six key components: simulation clock, activity flow, events and their sequencing, entities, resources, and queues.

- The simulation clock is used to keep execution in sync. The execution of tasks advances the simulation forward.
- Activity flow defines the sequencing of activity in the network. When one activity completes one of four things can happen: nothing, another activity begins, one of several activities begins, or more than one activity begins.
- Events are occurrences that drive execution. Execution, in turn, drives the simulation forward.
- Entities refer to representations flowing through the network, such as human operators.
- Resources constrain and limit execution, such as equipment and fuel.
- Queues are used to maintain order. When an event is scheduled it is placed into a queue. When the event completes it is removed, the clock is updated, and execution moves forward.

Human performance modeling. A human performance model (HPM) is used to represent human behavior in the context of specific systems and scenarios. A performance baseline can be achieved by placing the model of a human operator into simulation. Performance variability becomes visible by controlling system or scenario alterations. The data on this variability can then be quantified (e.g., task time, completion criteria, workload). Such a model has implications for system design and analysis.

The Combat Automation Requirements Testbed (CART) is an interface that provides meaningful interaction for human performance modeling. It integrates a model with the Goalsaint run-time engine, which is an application that generates and runs discrete-event simulation. CART allows a user to manipulate operator *goals* and task parameters that impact mission standards. Thus, CART represents the human operator as an information processor.

Human as an Information Processor

The basic concept of the human as an information processor (HIP) model is that the operator adapts and organizes tasks to meet current demands. Though a task allocation scheme defines the potential set of activities the operator can perform, the information processor model determines which task gets performed at a given time. Figure 1 is an HIP model adapted from Hendy and Farrell (1997).

The notion of goals is the central construct within the HIP elements. A mechanism is needed to sort and prioritize among concurrent demands to choose which goal(s) are serviced first, given that multiple mission demands can be active simultaneously. The model assumes that in a system-mission environment, the operator has an internal goal structure that helps assess and prioritize demands. These goals are the functions that must be performed successfully to accomplish the mission and are the "states" of the external environment that the operator seeks to control. During goal state evaluation, information from the environment (provided by perceptual processes) is compared with internally held knowledge about expectations of world states (rules) governing the conditions under which goals should become active. The goal state becomes active when the goal rule conditions are met.

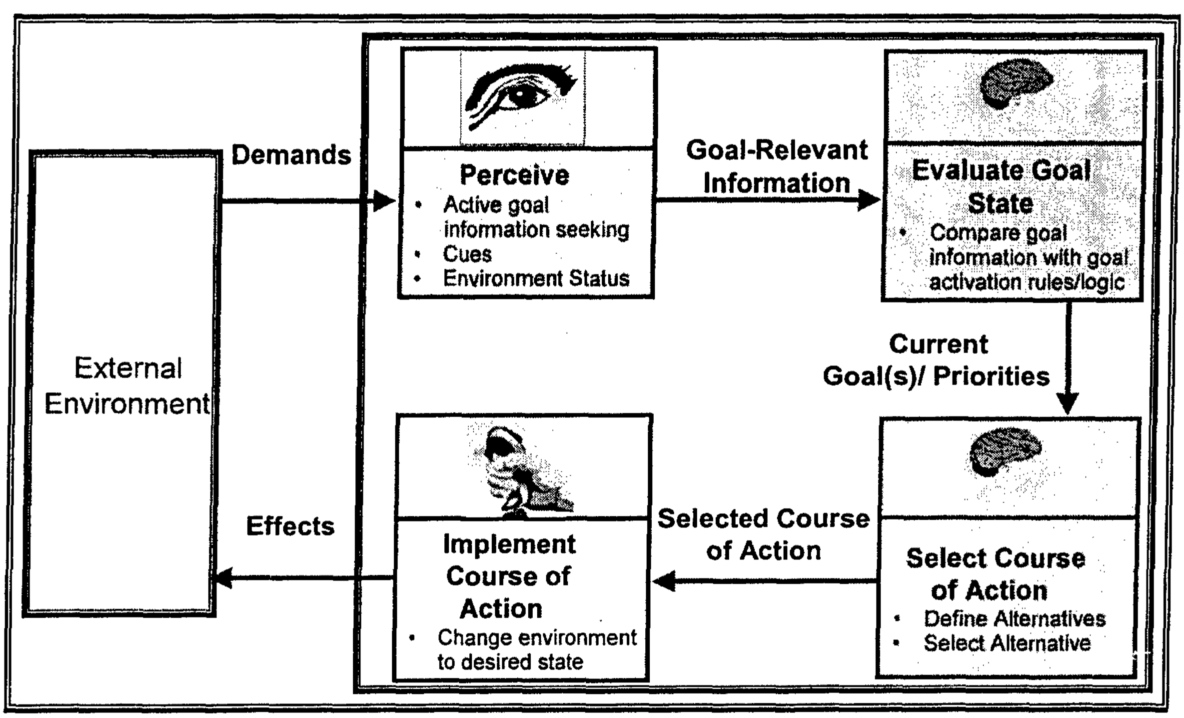

Figure 1. **Basic human information processing (HIP) model.**

Goals need information from the environment to determine when they become active. This information is obtained via operator perceptual processes, using the five senses. The 'Perceive' block in Figure 1 illustrates how these perceptual actions feed goals. Perception of demands is an active process in which the operator purposefully seeks specific information required by the particular goal set that is driving operator performance. Representing this perceptual activity in an HPM is important because such activity usually is not identified explicitly in task allocation schemes. Thus, it becomes an additional set of performances that can, in turn, constrain the core set of operator activities defined in task allocation. That is, the operator can only perform those tasks that need attention in which goal-relevant information has first been perceived.

Once goals become active, attention turns to selecting a course-of-action for bringing the current state of the world into the desired state. Course-of-action selection involves selecting the capabilities and methods for implementation that best accomplish the goal because there may be a number of capabilities that can be applied to achieve a goal. Course-of-action selection emphasizes decision making and usually involves a variety of cognitive processing skills (e.g., skill-based, rule-based, knowledge-based reasoning). Course-of-action selection also can involve other perceptual and action components that are applied to gain additional information needed to select an appropriate alternative. Again, this is a dimension of human performance not often addressed during the task allocation phase of system design. The specific requirements for course-of-action selection can be greatly influenced by the configuration of a system defined in an alternative (e.g., aircraft with on-board mission planners can significantly reduce pilot in-flight route re-planning workload versus aircraft without on-board planners). Like the perceptual activity described above, course-of-action selection is another 'overhead' activity associated with operators' management of their performance.

Once a course-of-action is selected, action is implemented. Generally, implementation involves motor activity (e.g., manipulate a control or throw a switch). Perceptual and cognitive activities are often involved when implementation activities are complex, in order to control and manage the implementation, dependent upon specific environmental conditions. The objective of course-of-action implementation is to produce an effect on the environment desired by a goal state on the environment (e.g., attack actions seek to destroy a target, evasion actions seek to evade a threat). Observation of effects is performed by perceptual capabilities, which, in turn, drive the goal states. The cycle repeats itself until the desired state is achieved. As in control theory, the information processor model is really a closed-loop control model (Flach, 1990).

Finally, HPMs must represent the limitation of perceptual, cognitive, and motor resources in terms of the number of concurrent activities an operator can support. In complex modern military environments, systems will place multiple and concurrent demands on the operator. As a result, the operator will have to simultaneously manage multiple active goal states. Active goals are dynamic and will shift in response to changing conditions in the mission environment. Thus, the activities associated with the active goals often compete for the same human performance resources (perceptual, cognitive, and motor). When demands exceed resources, excessive workload results, and the operator will engage in "workload mitigation" strategies to manage the demand (Hendy & Farrell, 1997). The operator might suspend or completely shed lower priority activities, might choose to simultaneously work two concurrent activities (which usually extends performance time for both activities as resources are shared between the two concurrent activities), or might employ a less mission-effective but more time-efficient solution for an activity. That is, during the process of applying these different workload mitigation strategies, some mission demands might not be met at all, others might not be met within the required time window, and still others might not be met because some other dimension of task performance (e.g., accuracy) is compromised. The net result of all possible workload effects is that mission performance can suffer. This result will be reflected as a consequence of correctly representing the number of concurrent activities that can be supported in the HPM.

COMBAT AUTOMATION REQUIREMENTS TESTBED (CART) PROGRAM

Design decisions made without proper consideration of the human factor often lead to design deficiencies that require remediation when found later in the design process, during operational testing, or in the field. This problem persists, in part, due to the lack of modeling tools that permit an appropriate representation of human performance to be readily developed and integrated with the constructive simulations used during trade studies (Martin, Anesgart, Hoagland, & Brett, 2001).

The Air Force Research Laboratory Human Effectiveness Directorate undertook the CART (Air Force Research Laboratory, 2001) program to address the lack of emphasis on crew-system issues within the modeling community. The program's vision is to provide the capability to evaluate total human-system performance in constructive acquisition trade studies through the use of realistic HPMs. The attendant goal is to develop and demonstrate human performance modeling and constructive simulation technologies. To this end, the program objective is to provide technology to enable engineers and analysts to develop and implement HPMs that can run as entities within constructive simulation environments to assess the performance of the human and system together at the level of mission effectiveness.

CART was developed through a partnership between the Air Force Research Laboratory and Science Applications International Corporation (SAIC), which adopted the framework proposed by Pew and Mavor (1998). Pew and Mavor articulated the need for "an integrative model that subsumes all or most of the contributors to human performance capacities and limitations" and noted that most integrative architectures view the human as an information processor.

CART adopted the US Army's relatively mature Improved Performance Research Integration Tool (IMPRINT) environment (Allender, Kelley, Salvi, Lockett, Headley, Promisel, Mitchell, Richer, & Feng, 1995). It extended IMPRINT's architecture to provide the ability to represent a human operator as a goal-oriented, dynamic, adaptive agent that modifies its performance as a situation changes. The underlying task-network modeling architecture offers relative simplicity in HPM design and permits explicit control of performance attributes.

This extended modeling environment allows the independent development of HPMs on personal computers. These HPMs can then be "holistically" connected to constructive system and environment models through standardized interfaces -- such as the High Level Architecture (HLA) or Distributed Interactive Simulation (DIS) protocols -- by using the extensions that CART made to the IMPRINT modeling environment.

This holistic constructive testbed integrates the operator, system, and mission environment and permits analysts to explore the complete constraint space associated with alternative system concepts and to vary the boundaries associated with each. This is valuable for the crew system designer because the constructive system and mission models provide opportunities to realistically represent these boundaries and to demonstrate boundary changes as a function of changes in system alternatives, including different levels of automation and operator abilities.

Figure 2 presents CART's architecture for integrating HPMs into engagement level simulations. It employs hybrid architecture (Pew & Mavor, 1998) for modeling human performance with task network modeling as the core human performance modeling method.

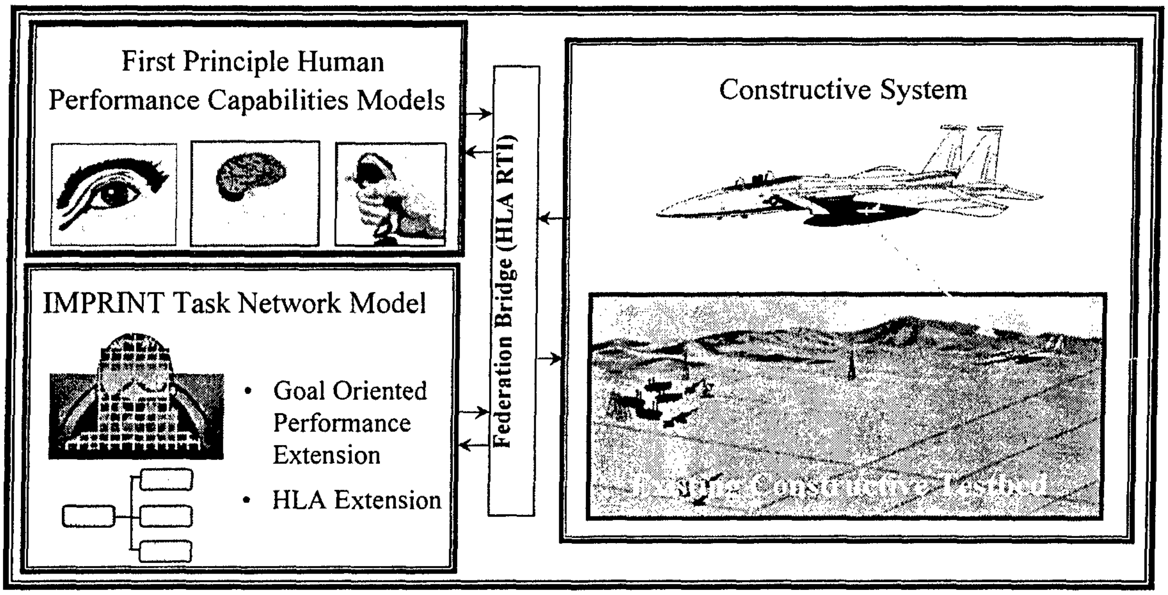

Figure 2. **CART human performance modeling architecture.**

CART extensions to IMPRINT are available beginning with IMPRINT version 6.40c. Additional details and instructions for obtaining IMPRINT are provided at: http://www.arl.army.mil/ARLDirectorates/HRED/imb/imprint/imprint.htm.

CART Case Studies

Two case studies have been conducted to demonstrate the tools and concepts of CART. Case study objectives included: (1) successfully developing and integrating an HPM into a constructive simulation environment, and (2) evaluating that model's performance against HITL performance in the same simulated environment in order to validate the HPM. For each case study, a military-problem domain was selected to demonstrate the benefits of constructive human-performance representation. Then, CART tools were applied to develop a model representing the relevant human performance. Next, the resulting HPM was interfaced with a constructive simulation of the mission environment, and multiple constructive trials carried out wherein Measures of Effectiveness (MOEs)[1] and Measures of Performance (MOPs)[2] data were collected. Finally, pilots or military operators conducted the same simulated missions in virtual HITL simulations, MOE and MOP data were collected for comparison to the HPM simulation results.

[1] MOEs measure the success in carrying out mission-level tasks, such as holding targets at risk or defeating threats.
[2] MOPs are typically quantitative measures of system characteristics, such as range, scan rate, or mass.

Case study 1: A strike fighter pilot model. The Virtual Strike Warfare Environment (VSWE) established by the Joint Strike Fighter Program Office for their air-to-ground-attack simulation evaluations was chosen for Case Study 1. The VSWE was developed to support various HITL simulations of envisioned Joint Strike Fighter missions for several trade studies. The VSWE consisted of an aircraft simulation with a generic cockpit interface that allowed pilot-in-the-loop control of the aircraft and its systems. The aircraft simulation was interfaced via shared memory to a simulated mission environment (terrain features, threats, targets, etc.). CART was used to develop an HPM representing pilot actions within a VSWE Time Sensitive Target (TST)[3] mission exercise (see Brett, Doyal, Malek, Martin, Hoagland, & Anesgart, 2002).

Case study 2: The intelligence, surveillance, & reconnaissance (ISR) section of a TST cell. For Case Study 2, CART evolved from modeling the performance of an individual to modeling that of a team. Specifically, the investigation centered on how well a CART HPM would account for team performance in the context of a TST Cell within an Aerospace Operations Center (AOC). Model development was limited to the detection, identification, geo-location, and monitoring activities of the intelligence, surveillance, and reconnaissance (ISR) section of the TST Cell. The model did not include detailed actions such as keystrokes or cursor movements as did the strike-fighter pilot model used in Case Study 1. A single HPM was developed to represent the information flow among a nine-person ISR-Section team (see Doyal, Goetz, Sargent, Overdorf, Brett, Martin, & Barbato, 2004; Martin, Barbato, & Doyal, 2003).

ORGANIC MODELING CAPABILITY

Organic Modeling Team

A major objective of this effort was to develop an in-house HPM and constructive simulation capability. Previous modeling efforts had been pursued through contracting. SAIC developed a strike fighter model and integrated it into a simulation environment used for a Joint Time Sensitive Targeting Project (Case study 1). SAIC experience was leveraged in our efforts to develop an in-house modeling capability. AFRL/HECI constructed a stand alone model (not HLA compliant) of a UAV SO as a first step. We planned to then venture out and construct models that could be integrated with HITL

[3] Time sensitive targets have an extremely limited time window of vulnerability, the attack of which is critical to ensure the successful execution of the Joint Task Force operations. They rank high on the joint integrated prioritized target list. (Hura, McLeod, Mesic, Sauer, Jacobs, Norton & Hamilton, 2002)

simulations. If these models are validated, they could be used to provide information on the human performance of military tasks. This information could aid the operating command in determining the operational capabilities of potential systems. The development of major weapon systems has been formalized into a process known as the Analysis of Alternatives. During the Analysis of Alternatives the findings from our models could be used to determine how design alternatives would affect the human operator's performance. This kind of information would then feed into choosing the best design alternative.

The OMT was assembled to become familiar with the tools and practices of human performance modeling and UAV systems. The branch's initiative to create organic capabilities was channeled through the team and the SO model.

Familiarization

Human performance modeling has not been a major focus of AFRL/HECI projects. The effort to bring this capability to the branch began with a two-fold process of familiarization for modeling and UAV systems.

Modeling. The team began by reviewing CART training materials. Contractor support (through SAIC) was a crucial first-step in becoming familiar with the CART interface and the software's capabilities. Hands-on training began with a simple model, developed as an exercise based upon a familiar procedure (pumping gas for a car), with guidance from SAIC. Several additional scenarios were modeled as the team became more adept with CART.

Micro Analysis and Design (MAAD) provided formal training on the CART software. MAAD specializes in discrete-event simulation software, and provides support to the CART program as a subcontractor to SAIC by adopting IMPRINT for Air Force needs. Two OMT members traveled to MAAD's headquarters in Boulder, Colorado for the week-long course.

UAV. The team took a three facet approach to understanding UAV systems. These included literature review, SME interviewing, and hands-on interaction with a UAV simulator located at AFRL/HECI. The literature (flight manual, training materials, etc) was useful in becoming familiar with system procedures and components. The insight gained from SMEs was useful in obtaining knowledge not directly evident in the literature. And team interaction with the simulator (including participation in a branch HITL study) provided first-hand knowledge of UAV systems. We measured the distances of the controls and displays using the UAV simulator. This information was needed later when we estimated the amount of time required to perform various SO tasks (i.e., manipulation of displays and controls).

UAV SENSOR OPERATOR MODEL

Mission Scenario

The setting for this mission is a commercial airport in a foreign country. Figure 3 illustrates the setting. An enemy cargo plane is using tarmac activity as cover for refueling purposes. The cargo plane is surrounded by armed soldiers and a refueling vehicle has been secured. Each terminal is servicing two commercial planes, their operation is suspended. The four commercial flights have been grounded. However, passengers are on board each plane and evacuation has been denied by the enemy.

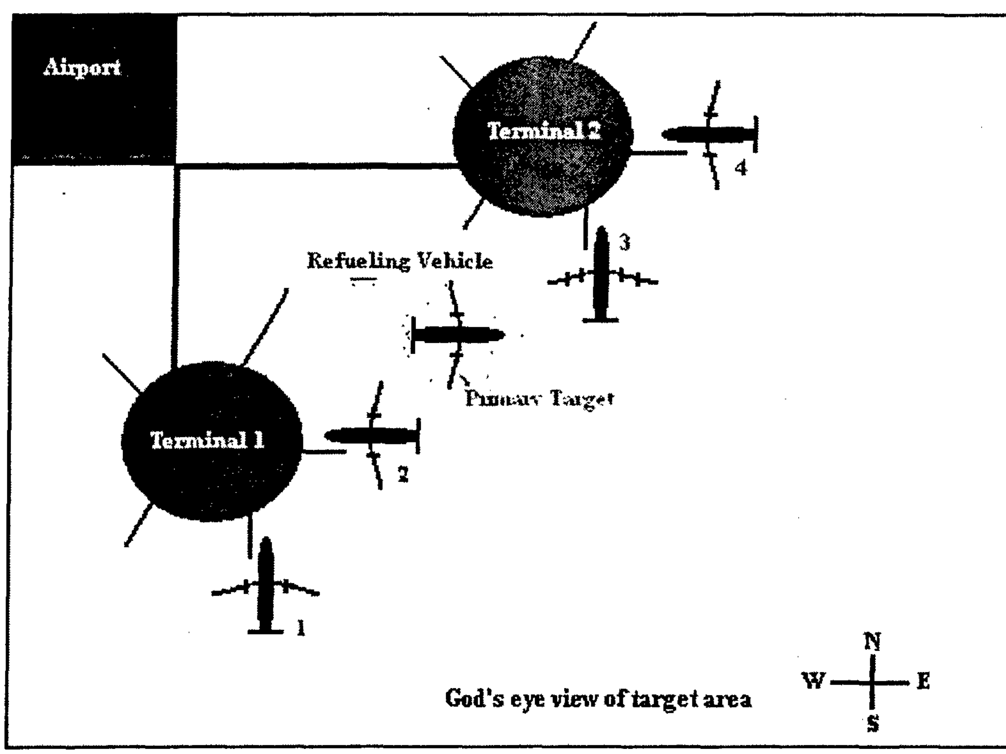

Figure 3. **God's-eye-view of target area.**

It is not believed that the enemy intends to preemptively interfere with the commercial carriers, short of ordering the stopping of evacuations. However, hostage and shielding situations are possible if a conflict ensues. The enemy might attempt to use a commercial plane to hide or smuggle small cargo. Plane 3 is bound for the United States.

It is suspected that the enemy is loading weapons and other illicit materials onto the cargo plane. Additionally, waste and other materials may be offloaded. Once the enemy plane has refueled it will move to the nearest runway and depart. There is no scheduled flight plan, the enemy is encroaching in restricted airspace; it is uncontrolled at arrival and departure.

A determination needs to be made about what kind of assault poses the least risk to civilians and the commercial carriers. Two alternatives are considered:

- A ground attack at the current location by a small and poorly trained security team waiting in the airport.
- An aerial attack immediately upon take-off by a strike force of ally planes patrolling the region.

The UAV is to approach the airport at 3,000 feet, well below controlled airspace. Upon reaching the perimeter of Terminal Radar Approach Control (TRACON) space, the UAV will take a glideslope to 1,000 feet and navigate just outside of the bottom layer of the "inverted wedding cake," approximately five miles from the target area holding at 1,000 feet.

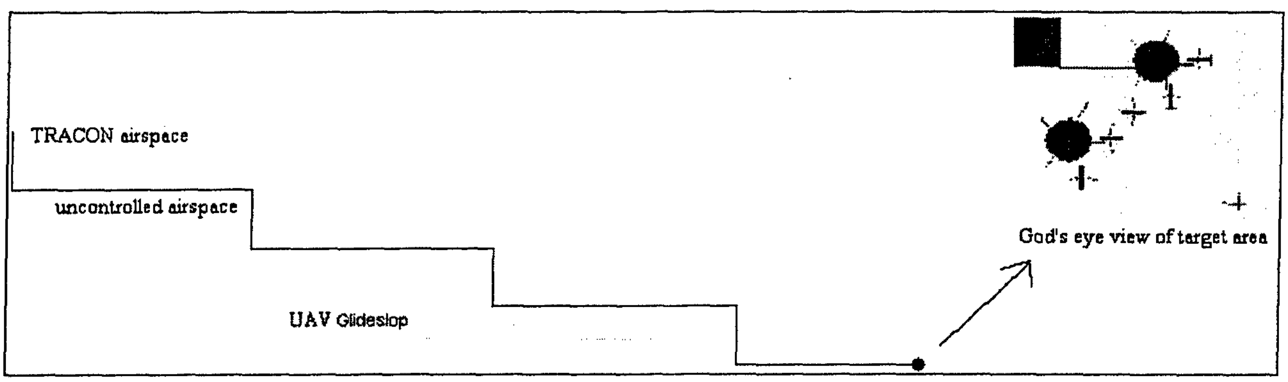

Figure 4. **Side view of UAV glideslope and location outside of TRACON space.**

Figure 4 shows a lateral view of the glideslope used to reach the position from which targets will be prosecuted. The dot on the right points to a picture of the target area.

The mission occurs during the day and excellent visibility is expected. The reconnaissance UAV will approach from the south, all terrain between the ground control station (GCS) and target area is desert. Adverse weather is not expected. No resistance will be encountered. The enemy soldiers at the target area cannot destroy the UAV at a distance of five miles. Additionally, TRACON space may not be entered as circling planes low on fuel must land immediately (no other serviceable site is available for redirection).

Table 1 summarizes the mission objectives. The primary objective is to gather information regarding the status of the enemy cargo plane that can be transmitted to an imagery analyst for further study. The secondary objective is to gather information regarding the four commercial aircraft. The tertiary objective is to conduct surveillance of the targeted area.

Table 1

Mission Objectives.

Level	Objective	Explanation
Primary	Gain Intel on the status of the enemy cargo plane that can be transmitted to an imagery analyst.	From the information collected, a determination will be made about a strike on the plane. Either on the ground or upon take-off, information gathered needs to determine if chemical weapons are onboard, making any strike too dangerous near the airport.
Secondary	Collect Intel on the status of the four commercial planes.	The multi-function operator (MFO) will determine if these planes are being used to smuggle materials, if any craft or passenger has been taken hostage, and if any systems have been corrupted. Extreme focus must be given to plane 3, a 747-400 "combi" bound for the US with passengers and cargo.
Tertiary	Perform surveillance.	If the enemy plane departs, information must be gathered to help determine that no dangerous elements have been left behind.

Mission Essential Elements of Information (EEIs)

1. Military cargo plane:
    a. Number of armed soldiers guarding the plane
    b. Location of refueling vehicle
    c. Contents of cargo loading/unloading
    d. Status of engines
2. Commercial planes:
    a. Status of engines
    b. Comprehensive view of target area
3. Surveillance:
    a. Maintain watch over tarmac area

Mission Attributes

These mission attributes will be considered true:

- Reconnaissance mission/UAV is not armed
- No hostiles en route
- Will not be engaged at target area
- Daytime
- No adverse weather conditions
- Passengers cannot evacuate the four commercial planes
- TRACON airspace is restricted
- Cargo plane may unexpectedly depart
- Day TV, IR (infrared), and SAR (Sensor Aperture Radar) capabilities
- Fuel is not an issue
- No crew rotations
- MFO is observing sensor data and operates the SAR

Implementing the scenario. The mission scenario was designed to use as much of the functionality contained in the UAV flight manual (United States Air Force, 2004) for sensor operators as possible. It was designed to enforce the functionality and tactics learned during familiarization.

The only portion of the mission that is modeled is the time spent at the target area. The beginning effect of the first task that supports function 1.0 (first function, highest level) begins the execution of EEI 1a. The activity flow is event driven: the SO progresses through the three objectives by accomplishing EEIs in order (there just so happens to be three objectives and three EEIs, one EEI per objective).

Two goal states are defined. The first goal state is to simply complete the mission. This goal state is the minimum needed to drive the activity flow. A second goal state is enacted at a random point by the departure of the cargo plane. When this occurs, the model breaks from the task network representing the mission to monitor the plane as it departs. This departure completes the new goal state. The model then returns to the original goal state and resumes the task network where it leaves off. This is represented by the SO completing EEIs.

Function and Task Decomposition

Appendix A provides the UAV SO function and task-level decomposition. This decomposition improved our understanding of the mission scenario from the SO's perspective and supported model development due to the network-based nature of discrete-event simulation. It is an exact outline of the discrete steps taken by the SO in the scenario. Appendix B provides the Task Information Spreadsheet, which is an outline of the decomposition applied to the model. This shows every task in the model, including dummy tasks and task parameters (both explained below).

Functions denote broad categories of activity performed by the human-machine system. These can be nested within other functions to create a hierarchy of related categories. The top-level functions are named by whole numbers (e.g., 1.0), subsequent functions are named by integers (e.g., 1.1, 1.2; 1.1.1, 1.2.1, etc.). Tasks denote the smallest unit of activity, recognized by the team, needed to serve a function of the human-machine system. A task cannot be broken down into smaller units; thus, where functions exist in a hierarchy, tasks are the bottom layer of the function decomposition.

Resolution. The tasks identified by the team do not necessarily represent the smallest unit of activity possible. Further decomposition would have been possible with more detailed research, and this could have represented the human-machine system more accurately. This level of detail was not reached in order to conserve time during the system familiarization phase. Given that the tasks do not represent the smallest unit of activity possible (they are comparable to a level of functions in a more detailed decomposition), the team was careful to maintain a consistent level of functionality across all tasks. Modelers can provide the level of detail contained within tasks; they need to be mindful to combine functionality from various tasks when several activities are being represented with fewer tasks (sacrificing resolution for simplicity) (Carretta, Doyal, & Craig, 2001).

Model Network

This section explores the relationship among networks in the model. The networks exist in a hierarchy where equal levels are denoted by numbers with equal decimal places (1.0 and 2.0; 1.1 and 2.1; 1.1.1 and 1.1.2, etc). The top-level contains the broadest categorization; the bottom-level contains tasking information that cannot be examined in any more detail (given the team's defined level of precision). All levels are comprised of functions except the bottom tasking level (the "button press" level). Functions on any level below the top are referred to as sub-functions, but represent the same conceptualization of further detail. The exploration here proceeds: **top level** (Figures 5 and 6) → **function 6.0** (Figure 7) → **sub-function 6.2** (Figure 8) → **sub-function 6.2.1.** (Figure 9). Tasks are seen in the network of sub-function 6.2.1.

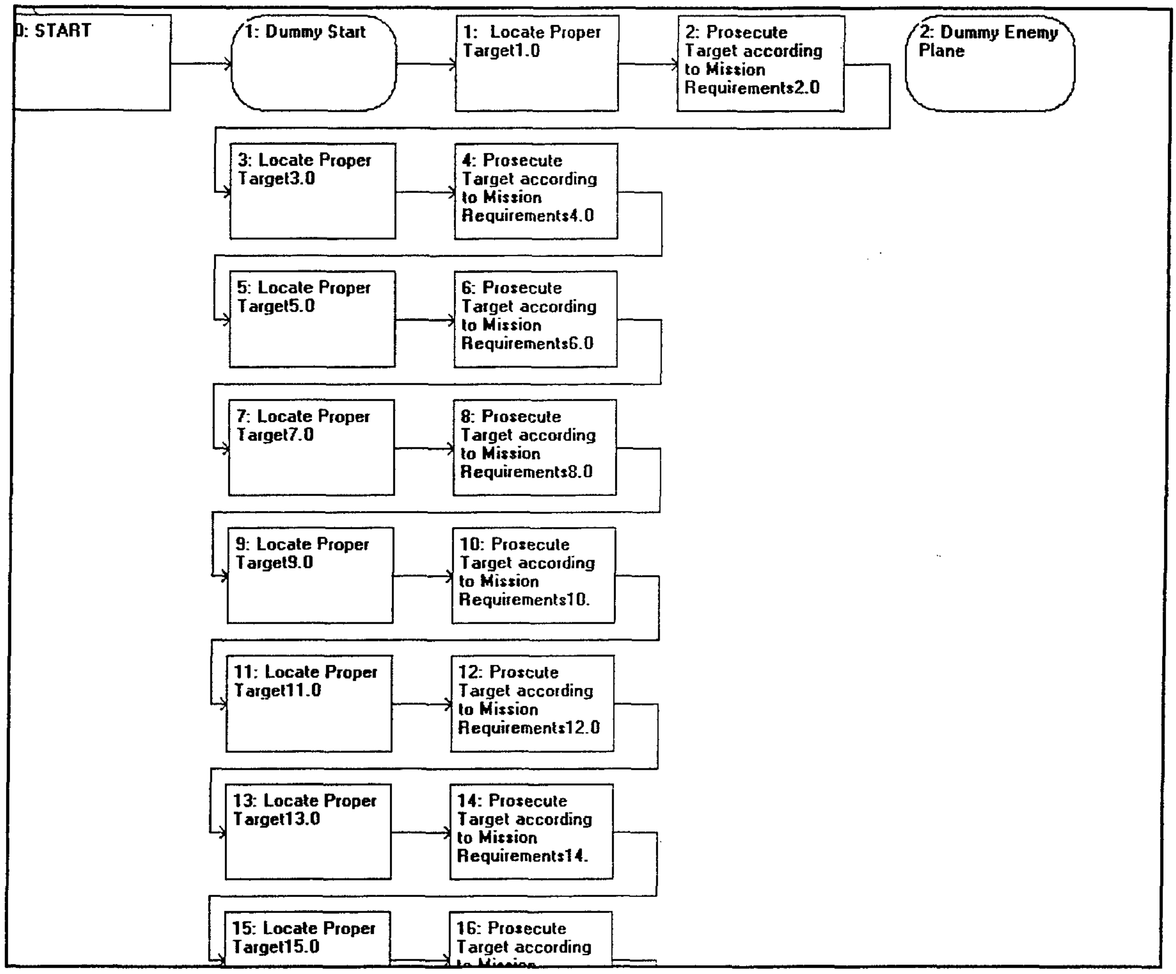

Figure 5. **Top-level model network (functions 1.0 through 16.0).**

The top level of the network is shown in Figure 5. It is comprised of functions denoted with whole numbers (1.0 through 18.0). These functions represent the broadest categories of organization within the model. Odd number functions pertain to locating targets (odd functions 1.0 through 15.0 are named "Locate Proper Target"). The sub-functions and tasks within these functions deal with determining and finding targets. Even number functions pertain to prosecuting targets (even functions 2.0 through 16.0 are named "Prosecute Target according to Mission Requirements"). The sub-functions and tasks within these deal with executing orders specific to each target. Functions 17.0 and 18.0 represent the execution of surveillance orders. This is the only part of the top-level categorization that does not follow the *locate* and *prosecute* trend. This can be seen at the bottom of Figure 6.

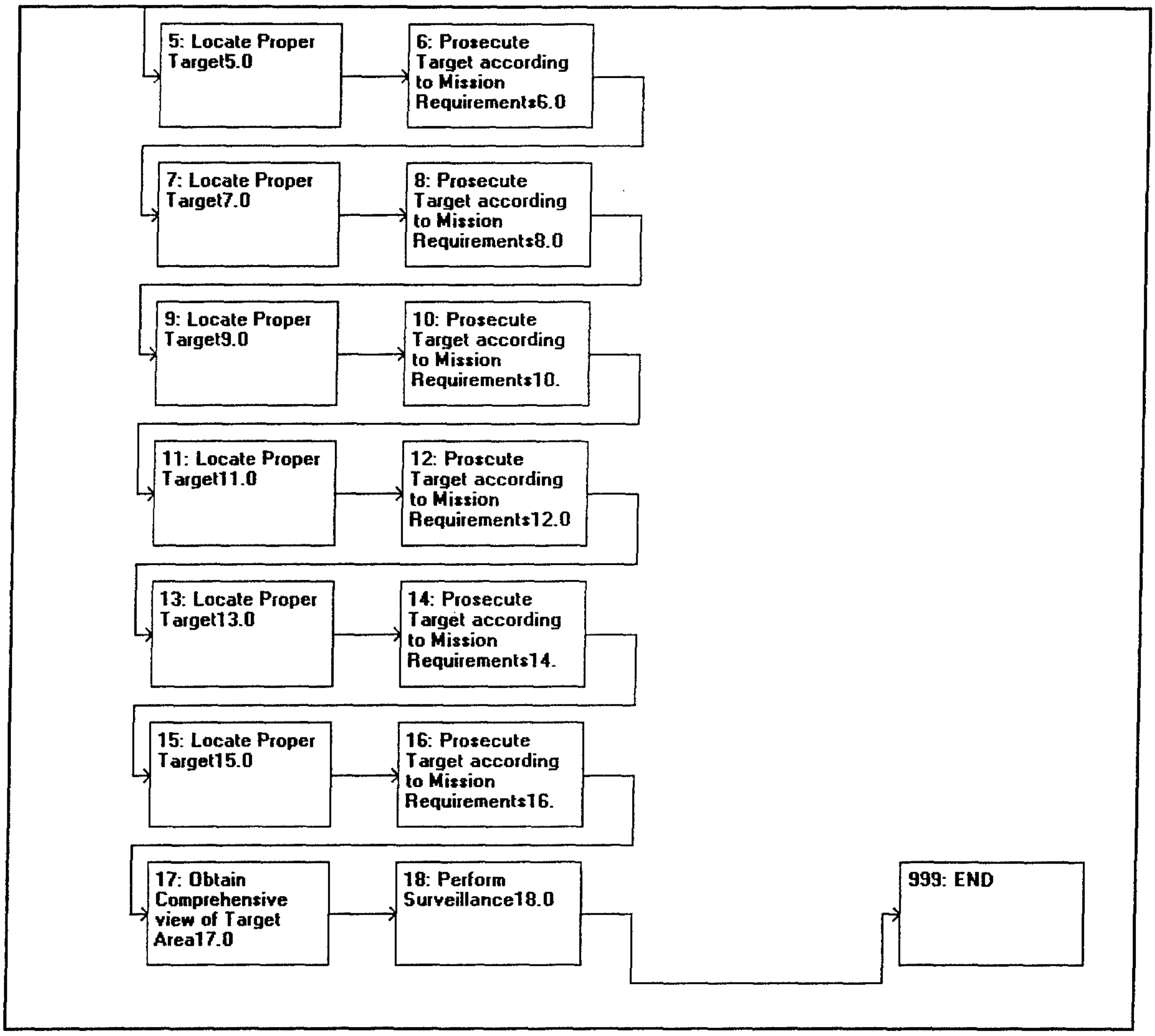

Figure 6. **Top-level network (functions 5.0 through 18.0).**

Within each top-level function is another network of sub-functions. Function 6.0 is explored in Figure 7.

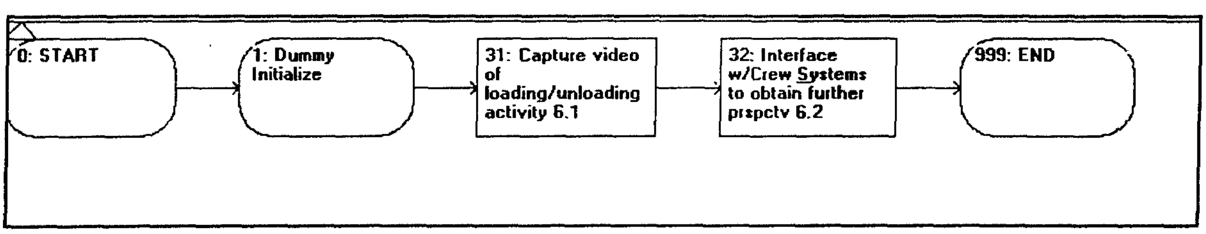

Figure 7. **The network within function 6.0.**

The networks within a top-level function serve to meet the purpose of that function, and are denoted with integers. For instance, the network within function 6.0 ("Prosecute Target according to

Mission Requirements") contains the actions that are necessary to record enemy activity around the target plane. This network is composed of two sub-functions. The first sub-function, 6.1 ("Capture video of loading/unloading activity"), describes the means by which the SO records enemy activity. Sub-function 6.2 ("Interface with Crew and Systems to obtain further perspective," Figure 8) describes what the SO must do to achieve several viewing angles. Together, sub-functions 6.1 and 6.2 fulfill the prosecution requirements of function 6.0.

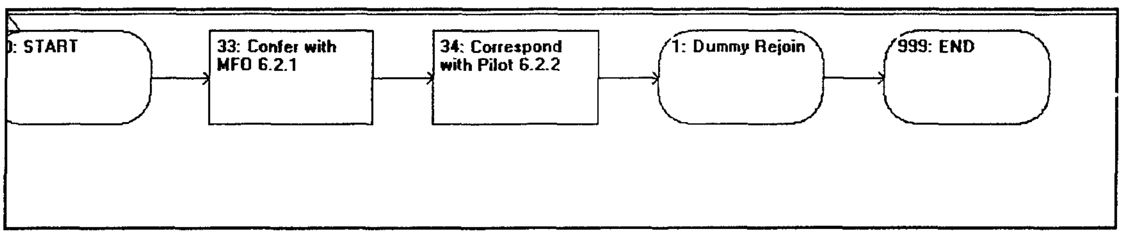

Figure 8. **The network within sub-function 6.2.**

Sub-functions 6.2.1 and 6.2.2 comprise the network of sub-function 6.2. These two sub-functions contain the functionality of sub-function 6.2. As shown in Figure 8, the SO must confer with the MFO and correspond with the pilot to accomplish sub-function 6.2. Within sub-function 6.2.1 (Figure 9), a network of tasks is used to accomplish the functionality of "Confer with MFO."

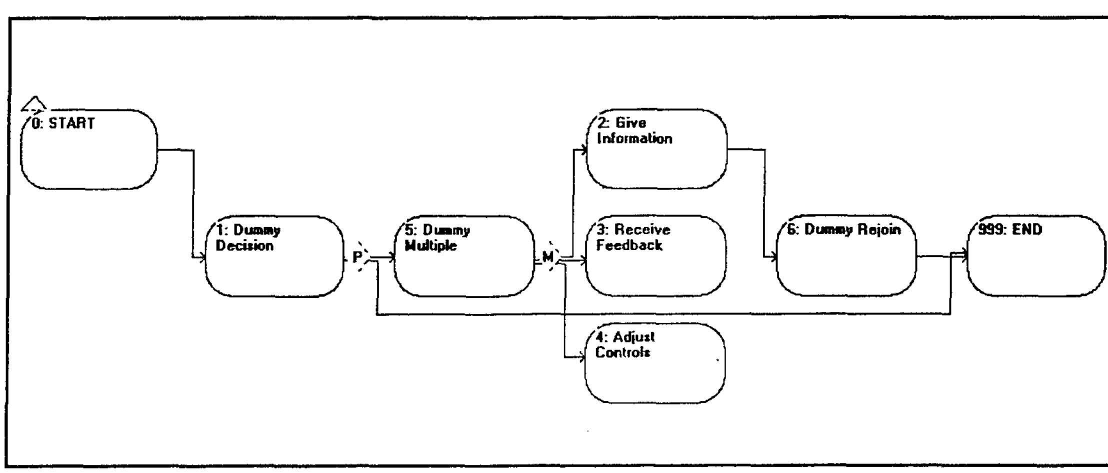

Figure 9. **The network within sub-function 6.2.1.**

A network of tasks is the lowest level of the network. Each task represents an action taken by the SO. A network of tasks represents a procedure. These procedures are conceptualized by the functions and sub-functions of higher levels.

The tasks that are contained within the model may differ from those in the function decomposition. This is due to the representation of reality in a computer-based model. In order to execute correctly, "dummy" tasks (seen in Figures 5, 7, 8, and 9) may be used to initialize variables or act as place holders. For instance, when entities must rejoin in a single task and proceed as one, a dummy task may be used to represent this rejoining. The rejoining of entities is of course something that does not happen in reality; therefore the dummy task is used without a time standard and does not contain any functionality. The functions and tasks used in the model can be seen in Appendix B.

Parameterization

Parameters that direct model execution can be defined for each task. There are six categories of task parameters in the CART interface:

- Time and Accuracy
- Effects
- Failure
- Workload
- Crew Assignments
- Taxon

For the UAV SO model, items in Time and Accuracy, Effects, Workload, and Crew Assignments were parameterized.

Time and accuracy. The CART interface provides a method for calculating task times based upon validated human factors and engineering research. The method is interfaced through micromodels that require various metrics and repetitions to be entered. This functionality allows a modeler to determine valid and reliable task times.

The Time and Accuracy parameter allows a modeler to enter time and accuracy estimates (means, standard deviations, distribution shapes) for each discrete task. Only values for the time statistic parameters were estimated for the SO model. All tasks were assumed to be performed with perfect accuracy.

- Mean time: provides a baseline from which task times are computed during execution. Mean time can be entered in numerical or expression form.
- Standard deviation: provides an estimate of the variability of the mean time estimated used during execution. If no deviation is entered the task will always execute at the mean time (i.e., no variability around the mean).
- Distribution parameter: provides information about the shape of the distribution.

Micromodels were used to compute task times, although several times were randomly chosen for tasks that were not well-defined. All standard deviations were half of the task mean time. Normal distributions were used to represent most tasks; Gamma distributions were used for tasks that would typically not deviate below the mean, such as response times. Appendix C provides a summary of the task times.

Effects. Effects parameters control changes in the model associated with a task beginning or ending. The three primary effects parameters are release conditions, beginning effects, and ending effects.

- Release condition: contains an expression evaluating whether or not a task can execute. Release conditions must evaluate to *true* for a task to begin execution. A condition that is not *true* "holds" a given task until some condition(s) returns a *true* value. The default expression is 1, every task will initially release. This parameter should not be used to define expressions.
- Beginning effect: contains an expression that indicates what happens when a task releases. This parameter defines or evaluates expressions that are dependent upon a task beginning. It is the first task effect evaluated once a task releases; what is determined by an expression here can affect those that follow in the same task.
- Ending effect: contains an expression that indicates what happens when a task concludes. These define or evaluate expressions that are dependent upon a given task completing.

Workload. The CART interface allows for the assignment of workload values to each task. These values are based on McCracken and Aldrich (1984): Visual, Auditory, Cognitive, Psychomotor (VACP; see Appendix D) approach to understanding operator workload. Workload for each task is estimated for each channel (visual, auditory, cognitive, and psychomotor) along a seven-point scale (0 - 7.0). Workload reports can be generated to provide a timeline of summed workload: between channels and across concurrent tasks. They do not indicate an overall effect on the operator. An explanation of workload assignments for the UAV SO tasks is provided in Appendix E.

Crew assignments. The CART interface can assign tasks to various operators. When there are multiple operators, one must be designated as the primary operator (a single operator defaults as the primary). This parameter helps to accurately represent multiple-operator systems. The goal orientation functionality in CART is only compatible with the primary operator. Thus, the tasks associated with this primary operator drive execution, other operators only serve to support the representation of reality. The team assigned the UAV SO as the primary operator, with a majority of the tasks. Several tasks dealing with the use of the Sensor Aperture Radar (SAR) were assigned to the MFO, as this position can serve as the SAR operator in live UAV missions.

Variables. Variables are used to represent changeable aspects of a system that is being simulated. Each variable has a fixed name but can vary in value given occurrences in the scenario, according to the modeler's specifications. Two types of variables exist, real and integer. These represent real and integer numbers respectively. Variables can also have external model calls, which interface with HLA but were not used in this project. The Variable Catalogue is given in Appendix F.

Modeling

The modeling process began slowly. Only one team member had prior experience with human performance modeling and the CART interface. Thus, team efforts doubled during the system familiarization phase of the project to include learning the functionality and techniques of CART. Two team members (neither of whom had any prior exposure with CART) attended a training class at Micro Analysis and Design in Boulder, CO. The team also generated several practice models, based upon familiar processes, with the help of SAIC contractors in the CART Program. Modeling began for the assigned model three months after the Organic Modeling Team's formation and subsequent assignment to do so. The first three months were an intense period of familiarization with both the UAV system and CART software.

Work on the assigned model progressed at varying rates. Progress was achieved both quickly and laboriously. The team was able to apply what had been learned and worked independently, however SAIC contractors were also consulted to help debug the model and work through problems.

A simplistic model was created. Future constructive modeling efforts should reach the same level of detail much more quickly. Further, the team feels that it is ready to work on projects that could be subjected to verification and validation.

The assignment was designated as a learning experience from the outset. The ultimate goal of the project was to familiarize the team with the process of human performance modeling; the UAV system was chosen as the modeling platform because of the branch's current emphasis on UAV operations. The team acknowledged the purpose of this assignment and gave more attention to implementing CART functionality than constructing a valid model.

FUTURE DIRECTIONS

Stand-alone human performance models such as the UAV SO model developed in this study have only limited value. While they are useful for describing the discrete task sequences performed by an individual, they cannot be used to represent a human interacting with others as a member of a team. The development of an HPM that can interact with other HPMs and/or with humans in a virtual simulation allows us to address more complex issues (e.g., team performance where all but one team member can be consistently represented with HPMs). For instance, an interactive UAV SO HPM could represent a crewmember for human UAV pilots who are evaluating new system Concept of Operation (CONOPS) or new control and display concepts in a virtual simulation environment. To do so requires additional programming to create the linkage between the constructive and virtual simulations.

Several potential follow-on applications of human performance modeling and constructive simulation have been identified. One already mentioned would be to integrate the UAV SO model with a UAV virtual simulation environment.

A second application could be to explore proposed new CONOPS for an existing system. For example, can UAV pilots control multiple aircraft using existing technology without performance decrement? Is additional functionality (e.g., automatic target curing, autopilot) needed to assist the pilot controlling multiple UAVs?

Another application would be to develop CONOPS for systems that do not yet exist. For example, a set of performance requirements (e.g., destroy a time critical target within 5 minutes of its identification) might be proposed for a weapon system that does not yet exist (e.g., next-generation bomber). Constructive models could be used to establish a performance baseline for a current system (e.g., B-1 bomber) attempting to meet the new requirements to determine shortfalls in performance. Additional constructive models could be developed to estimate the effects of proposed new technology (e.g., airframe, engines) on achieving the new requirements.

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GLOSSARY

CART	Combat Automation Requirements Testbed
EEI	Essential Element of Information
HITL	Human-in-the-Loop
HLA	High Level Architecture
HPM	Human Performance Model
IMPRINT	Improved Performance Research Integration Tool
MFO	Multi-Function Operator
OMT	Organic Modeling Team
SAIC	Science Applications International Corporation
SAR	Sensor Aperture Radar
SME	Subject-Matter-Expert
SO	Sensor Operator
TRACON	Terminal Radar Approach Control
UAV	Unmanned Aerial Vehicle
VACP	Visual, Auditory, Cognitive, Psychomotor
VSWE	Virtual Strike Warfare Environment

APPENDIX A. FUNCTION DECOMPOSITION

Notes. Analysis: UAV SO; Mission: Sensor Operator – stand alone

Brackets {} denote team notes about model construction

Mission Level Goal: Complete Mission
PRIMARY OBJECTIVE: EEI 1a-1d
EEI 1a

1.0 Locate Proper Target
- 1.1 Slew Ball
    - Attend to Tracker Display
    - Set Cursor
    - Execute Lat button presses
    - Press Tab
    - Execute Long button presses
    - Press Enter
    - Attend to HUD
- 1.2 Confirm Target as Correct
    - Consult Target DEC
    - Compare to Image on HUD
    - Decide if Correct Target is in view for Prosecution (decision)
    - {Begin target search (not described) or move on to Function 2.0}

2.0 Prosecute Target according to Mission Requirements
- 2.1 Perform Initial Count of Soldiers
    - Switch to Rate Mode
    - Count Soldiers visible in HUD image
    - Confer with MFO
    - Decide if further Perspective(s) is needed (decision)
    - Zoom out to Global View
    - {move on to Goal 2 or go to Function 2.2 (always)}
- 2.2 Interface with Crew and Systems to obtain further Perspective(s)
    - 2.2.1 Correspond with Pilot (multiple with 2.2.2)
        - Give Directions (and) Respond to Feedback
    - 2.2.2 Perform Further Counts (multiple with 2.2.1)
        - Adjust Controls (and) Continue Counting Soldier
        - Decide if all that can be counted are confirmed (decision) {go to next task (always) or repeat from Function 2.2.1}
        - Zoom out to Global View {move on to EEI 1b}

EEI 1b

3.0 Locate Proper Target
- 3.1 Determine next Target
    - Consult Target DEC
- 3.2 Locate Refueling Vehicle
    - Attend to HUD
    - Confirm that Pilot has Global View
    - Perform Target Search

4.0 Prosecute Target according to Mission Requirements
- 4.1 Lock Camera on Target with Feature or Point Track
    - Set Track Gate on Target
    - Press Joystick Trigger to Second Detent
- 4.2 Maintain Image long enough for MFO to determine status
    - Zoom in and out as necessary

- Confer with MFO
- Release Track Mode via Joystick Trigger
- Zoom out to Global View. {move on to EEI 1c}

EEI 1c

5.0 Locate Proper Target

5.1 Determine next Target

- Consult Target DEC

5.2 Locate Activity at rear of plane

- Attend to HUD
- Confirm that pilot has Global View
- Perform Target Search
- Zoom in on target area

6.0 Prosecute Target according to Mission Requirements

6.1 Capture video of loading/unloading activity

- Confer with MFO about activity
- Manipulate Camera as necessary
- Decide if further Perspective(s) is needed (decision)
- {Function 6.2 (always) or EEI 1d}

6.2 Interface with Crew and Systems to obtain further Perspective(s)

6.2.1 Confer with MFO

- Give Information (and) Receive Feedback (and) Adjust Controls

6.2.1 Correspond with Pilot

- Give Directions (and) Respond to Feedback
- Zoom out to Global View {move on to EEI 1d}

EEI 1d

7.0 Locate Proper Target

7.1 Determine next Target

- Consult Target DEC

7.2 Locate Engines

- Attend to HUD
- Confirm that Pilot has Global View
- Perform Target Search
- Zoom in on Starboard Engine

8.0 Prosecute Target according to Mission Requirements

8.1 Determine Status of First Engine

- Switch to Spotter Mode
- Switch to IR
- Report Status of Engine {color} to MFO

8.2 Obtain Image of Second Engine

- Switch to Rate Mode
- Switch to Day TV
- Zoom out to Global View
- Confirm that Pilot still has Global View
- Zoom in on Port Engine

8.3 Determine Status of Second Engine

- Switch to Spotter Mode
- Switch to IR
- Report Status of Engine {color} to MFO
- Switch to Rate Mode
- Switch to Day TV
- Zoom out to Global View {move on to EEI 2a}

SECONDARY OBJECTIVE: EEI 2a-2b
EEI 2a
9.0 Locate Proper Target
- 9.1 Determine Next Target
  - Consult Target DEC
- 9.2 Locate Commercial Plane 1
  - Attend to HUD
  - Confirm that Pilot has Global View
  - Perform Target Search
  - Zoom in on Target

10.0 Prosecute Target according to Mission Requirements
- 10.1Determine Status of First Engine
  - Switch to Spotter Mode
  - Switch to IR
  - Report Status of Engine {color} to MFO
- 10.2 Obtain Image of Second Engine
  - Switch to Rate Mode
  - Switch to Day TV
  - Zoom out to Global View
  - Confirm that Pilot has Global View
  - Zoom in on Engine
- 10.3Determine Status of Second Engine
  - Switch to Spotter Mode
  - Switch to IR
  - Report Status of Engine {color} to MFO
  - Switch to Rate Mode
  - Switch to Day TV
  - Zoom out to Global View

11.0 Locate Proper Target
- 11.1Determine Next Target
  - Consult Target DEC
- 11.2Locate Commercial Plane 2
  - Attend to HUD
  - Confirm that Pilot has Global View
  - Perform Target Search
  - Zoom in on target

12.0 Prosecute Target according to Mission Requirements
- 12.1Determine Status of First Engine
  - Switch to Spotter Mode
  - Switch to IR
  - Report Status of Engine {color} to MFO
- 12.2 Obtain Image of Second Engine
  - Switch to Rate Mode
  - Switch to Day TV
  - Zoom out to Global View
  - Confirm that Pilot has Global View
  - Zoom in on Engine
- 12.3Determine Status of Second Engine
  - Switch to Spotter Mode
  - Switch to IR
  - Report Status of Engine {color} to MFO
  - Switch to Rate Mode
  - Switch to Day TV

- Zoom out to Global View

13.0 Locate Proper Target

13.1Determine Next Target

- Consult Target DEC

13.2Locate Commercial Plane 3

- Attend to HUD
- Confirm that Pilot has Global View
- Perform Target Search
- Zoom in on target

14.0 Prosecute Target according to Mission Requirements

14.1Determine Status of First Engine

- Switch to Spotter Mode
- Switch to IR
- Report Status of Engine {color} to MFO

14.2 Obtain Image of Second Engine

- Switch to Rate Mode
- Switch to Day TV
- Zoom out to Global View
- Confirm that Pilot has Global View
- Zoom in on Engine

14.3Determine Status of Second Engine

- Switch to Spotter Mode
- Switch to IR
- Report Status of Engine {color} to MFO
- Switch to Rate Mode
- Switch to Day TV

14.4Obtain Image of Third Engine

- Zoom out to Global View
- Confirm that Pilot has Global View
- Zoom in on Engine

14.5Determine Status of Third Engine

- Switch to Spotter Mode
- Switch to IR
- Report Status of Engine {color} to MFO
- Switch to Rate Mode
- Switch to Day TV

14.6Obtain Image of Fourth Engine

- Zoom out to Global View
- Confirm that Pilot has Global View
- Zoom in on Engine

14.7Determine Status of Fourth Engine

- Switch to Spotter Mode
- Switch to IR
- Report Status of Engine {color} to MFO
- Switch to Rate Mode
- Switch to Day TV
- Zoom out to Global View

15.0 Locate Proper Target

15.1Determine Next Target

- Consult Target DEC

15.2Locate Commercial Plane 4

- Attend to HUD
- Confirm that Pilot has Global View

- Perform Target Search
- Zoom in on target

16.0 Prosecute Target according to Mission Requirements

16.1Determine Status of First Engine

- Switch to Spotter Mode
- Switch to IR
- Report Status of Engine {color} to MFO

16.2 Obtain Image of Second Engine

- Switch to Rate Mode
- Switch to Day TV
- Zoom out to Global View
- Confirm that Pilot has Global View
- Zoom in on Engine

16.3Determine Status of Second Engine

- Switch to Spotter Mode
- Switch to IR
- Report Status of Engine {color} to MFO
- Switch to Rate Mode
- Switch to Day TV
- Zoom out to Global View {move on to EEI 2b}

EEI 2b

17.0Obtain Comprehensive view of Target area

17.1Determine Next Target

- Consult Target DEC

17.2Position Craft for Prosecution

- Attend to HUD
- Communicate with Pilot

17.3Employ SAR

- Activate SAR
- Take various pictures {move on to EEI 3a}

TERTIARY OBJECTIVE: EEI 3a

EEI 3a

18.0Perform Surveillance

18.1Determine Next Target

- Consult Target DEC

18.2Monitor area

- Watch for Pop up Threats (multiple with following)
- Check that no soldiers are left
- Check that no suspicious objects left
- Confirm that airport operations returning to normal
- Begin assisting in return flight

<u>Second Goal State: Monitor Plane</u>

PRIMARY OBJECTIVE

19.0Monitor Enemy Plane During Take-off

- Monitor 1
- Monitor 2
- Monitor 3

APPENDIX B. TASK INFORMATION SPREADSHEET

Notes. Analysis: UAV SO; Mission: Sensor Operator – stand alone

Task number	Task name	Time standard	Standard dev	V	A	C	P	Crew
I	Dummy Start							
II	Dummy Enemy Plane							
1.0	**Locate Proper Target**							
1.1	**Slew Ball**							
1	Attend to Tracker Display	0:00:00.5	00:00:00.25 Gama	1.0	0	0	1.0	SO
2	Set Cursor	0:00:01.73	0:00:00.92 Norm	5.0	0	0	2.2	SO
3	Execute Lat Button Presses	0:00:01.60	0:00:00.46 Norm	5.9	0	1.0	7.0	SO
4	Press Tab	0:00:00.51	0:00:00.26 Norm	5.9	0	1.0	2.2	SO
5	Execute Long Button Presses	0:00:01.60	0:00:00.92 Norm	5.9	0	1.0	7.0	SO
6	Press Enter	0:00:00.51	0:00:00.26 Norm	5.9	0	1.0	2.2	SO
7	Attend to HUD	0:00:00.50	0:00:00.25 Gama	1.0	0	0	1.0	SO
1.2	**Confirm Target as Correct**							
8	Consult Target DEC	0:00:04.03	0:00:02.02 Gama	5.9	0	3.7	4.6	SO
9	Compare to Image on HUD	0:00:02.50	0:00:01.25 Norm	4.0	0	6.8	1.0	SO
10	Decide if Correct Target is in view for Prosecution	0:00:00.0	0:00:00.0	0	0	7.0	0	SO
2.0	**Prosecute Target According to Mission Reqts**							
III	Dummy Initialize							
2.1	**Perform Initial Count of Soldiers**							

IV	Dummy Decision							
11	Switch to Rate Mode	0:00:00.50	0:00:00.25 Norm	0	0	1	2.2	SO
12	Count Soldiers visible in HUD Image	0:00:20.10	0:00:10.05 Norm	7.0	0	6.8	5.8	SO
13	Confer with MFO	0:00:04.82	0:00:02.41 Norm	4.0	4.9	5.3	1.0	SO
14	Decide if further Perspective(s) is needed	0:00:00.0	0:00:00.0	0	0	6.8	0	SO
15	Zoom out to Global View	0:00:01.0	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
2.2	**Interface w/Crew and Systems to obtain...**							
2.2.1	**Correspond with Pilot**							
16	Give Directions	0:00:08.62	0:00:04.31 Norm	5.0	0	6.8	1.0	SO
17	Respond to Feedback	0:00:08.62	0:00:04.31 Norm	0	4.9	5.3	1.0	SO
V	Dummy Rejoin							
2.2.2	**Perform Further Counts**							
18	Adjust Controls	0:03:00.0	0:01:50.0 Norm	5.4	0	6.8	7.0	SO
19	Continue Counting Soldiers	0:00:20.1	0:00:10.05 Norm	7.0	0	6.8	5.8	SO
VI	Dummy Rejoin							
20	Decide if all that can be counted are confirmed	0:00:00.0	0:00:00.0	0	0	6.8	0	SO
21	Zoom out to Global View	0:00:01.0	0:00:00.0 Gama	3.7	0	1.0	5.8	SO
VII	Dummy Rejoin							
3.0	**Locate Proper Target**							
VIII	Dummy Initialize							
3.1	**Determine Next Target**							
22	Consult Target DEC	0:00:04.03	0:00:02.02 Gama	5.9	0	3.7	4.6	SO
3.2	**Locate Refueling Vehicle**							
23	Attend to HUD	0:00:00.50	0:00:00.25 Gama	1.0	0	0	1.0	SO
24	Confirm that Pilot has Global View	0:00:03.06	0:00:01.53 Norm	1.0	4.9	3.7	1.0	SO
25	Perform Target Search	0:01:00.0	0:00:50.0 Norm	7.0	0	6.8	7.0	SO

4.0	**Prosecute Target According to Mission Reqts**							
4.1	**Lock Cam on Target w/Feature or Point Track**							
26	Set Track Gate on Target	0:00:01.86	0:00:00.93 Norm	5.0	0	0	2.2	SO
27	Press Joystick Trigger to Second Detent	0:00:00.04	0:00:00.02 Norm	0	0	0	2.2	SO
4.2	**Maintain Image long enough for MFO...**							
28	Zoom in and out as necessary	0:00:02.0	0:00:01.0 Norm	5.0	0	3.7	5.8	SO
29	Confer with MFO	0:00:04.82	0:00:02.41 Norm	4.0	4.9	5.3	1.0	SO
30	Release Track Mode via Joystick Trigger	0:00:00.04	0:00:00.02 Norm	0	0	0	2.2	SO
31	Zoom out to Global View	0:00:01.0	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
5.0	**Locate Proper Target**							
5.1	**Determine Next Target**							
32	Consult Target DEC	0:00:04.03	0:00:02.02	5.9	0	3.7	4.6	SO
5.2	**Locate Activity at Rear of Plane**							
33	Attend to HUD	0:00:00.50	0:00:00.25 Gama	1.0	0	0	1.0	SO
34	Confirm that Pilot has Global View	0:00:03.06	0:00:01.00 Gama	5.0	0	3.7	5.8	SO
35	Perform Target Search	0:00:30.0	0:00:15.0 Norm	7.0	0	6.8	.0	SO
36	Zoom in on Target Area	0:00:01.0	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
6.0	**Prosecute Target According to Mission Reqts**							
IX	Dummy Initialize							
6.1	**Capture video of loading/unloading activity**							
37	Confer with MFO about Activity	0:00:04.82	0:00:02.41 Norm	4.0	4.9	5.3	1.0	SO
38	Manipulate Camera as necessary	0:00:15.0	0:00:07.50 Norm	5.0	0	3.7	5.8	SO
39	Decide if further Perspective(s) is needed	0:00:00.0	0:00:00.0	0	0	6.8	0	SO
6.2	**Interface w/Crew and Systems to obtain...**							

6.2.1	**Confer with MFO**							
X	Dummy Decision							
XI	Dummy Multiple							
40	Give Information	0:00:09.12	0:00:04.56 Norm	5.0	0	6.8	1.0	SO
41	Receive Feedback	0:00:10.42	0:00:05.21 Norm	0	4.9	5.3	0	SO
42	Adjust Controls	0:00:20.0	0:00:10.0 Norm	5.4	0	6.8	7.0	SO
XII	Dummy Rejoin							
6.2.2	**Correspond with Pilot**							
XIII	Dummy Skip							
XIV	Dummy Path							
43	Give Directions	0:00:08.62	0:00:04.31 Norm	5.0	0	6.8	1.0	SO
44	Respond to Feedback	0:00:08.62	0:00:04.31 Norm	0	4.9	5.3	1.0	SO
XV	Dummy Rejoin							
45	Zoom out to Global View	0:00:01.0	0:00:00.05 Gama	3.7	0	1.0	5.8	SO
XVI	Dummy Rejoin							
7.0	**Locate Proper Target**							
7.1	**Determine Next Target**							
46	Consult Target DEC	0:00:04.03	0:00:02.02 Gama	5.9	0	3.7	4.6	SO
7.2	**Locate Engines**							
47	Attend to HUD	0:00:00.50	0:00:00.25 Gama	1.0	0	0	1.0	SO
48	Confirm that Pilot has Global View	0:00:03.60	0:00:01.80 Norm	1.0	4.9	3.7	1.0	SO
49	Perform Target Search	0:00:30.0	0:00:15.0 Norm	7.0	0	6.8	7.0	SO
50	Zoom in on Starboard Engine	0:00:01.0	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
8.0	**Prosecute Target According to Mission Reqts**							
8.1	**Determine Status of First Engine**							
51	Switch to Spotter Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO

52	Switch to IR	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
53	Report Status of Engine to MFO	0:00:05.17	0:00:02.59 Norm	4.0	0	4.6	1.0	SO
8.2	**Obtain Image of Second Engine**							
54	Switch to Rate Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
55	Switch to Day TV	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
56	Zoom out to Global View	0:00:01.0	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
57	Confirm that Pilot has Global View	0:00:03.06	0:00:01.53 Norm	1.0	4.9	3.7	1.0	SO
58	Zoom in on Port Engine	0:00:01.0	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
8.3	**Determine Status of Second Engine**							
59	Switch to Spotter Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
60	Switch to IR	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
61	Report Status of Engine to MFO	0:00:05.17	0:00:02.59 Norm	4.0	0	4.6	1.0	SO
62	Switch to Rate Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
63	Switch to Day TV	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
64	Zoom out to Global View	0:00:01.0	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
9.0	**Locate Proper Target**							
9.1	**Determine Next Target**							
65	Consult Target DEC	0:00:04.03	0:00:02.02 Gama	5.9	0	3.7	4.6	SO
9.2	**Locate Commercial Plane 1**							
66	Attend to HUD	0:00:00.50	0:00:00.25 Gama	1.0	0	0	1.0	SO
67	Confirm that Pilot has Global View	0:00:03.06	0:00:01.53 Norm	1.0	4.9	3.7	1.0	SO
68	Perform Target Search	0:00:30.0	0:00:15.00 Norm	7.0	0	6.8	7.0	SO

69	Zoom in on Target	0:00:01.0	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
10.0	**Prosecute Target According to Mission Reqts**							
10.1	**Determine Status of First Engine**							
70	Switch to Spotter Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.2	2.2	SO
71	Switch to IR	0:00:00.50	0:00:00.25 Norm	0	0	1.2	2.2	SO
72	Report Status of Engine to MFO	0:00:05.17	0:00:2.59 Norm	4.0	0	4.6	1.0	SO
10.2	**Obtain Image of Second Engine**							
73	Switch to Rate Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
74	Switch to Day TV	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
75	Zoom out to Global View	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
76	Confirm that Pilot has Global View	0:00:03.06	0:00:01.53 Norm	1.0	4.9	3.7	1.0	SO
77	Zoom in on Engine	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
10.3	**Determine Status of Second Engine**							
78	Switch to Spotter Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
79	Switch to IR	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
80	Report Status of Engine to MFO	0:00:05.17	0:0:02.58 Norm	4.0	0	4.6	1.0	SO
81	Switch to Rate Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
82	Switch to Day TV	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
83	Zoom out to Global View	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
11.0	**Locate Proper Target**							
11.1	**Determine Next Target**							
84	Consult Target DEC	0:00:04.03	0:00:02.02 Gama	5.9	0	3.7	4.6	SO
11.2	**Locate Commercial Plane 2**							

85	Attend to HUD	0:00:00.50	0:00:00.25 Gama	1.0	0	0	1.0	SO
86	Confirm that Pilot has Global View	0:00:03.06	0:00:01.53 Norm.	1.0	4.9	3.7	1.0	SO
87	Perform Target Search	0:00:30.00	0:00:15.00 Norm	7.0	0	6.8	7.0	SO
88	Zoom in on Target	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
12.0	**Prosecute Target According to Mission Reqts**							
12.1	**Determine Status of First Engine**							
89	Switch to Spotter Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
90	Switch to IR	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
91	Report Status of Engine to MFO	0:00:05.17	0:00:02.59 Norm	4.0	0	4.6	1.0	SO
12.2	**Obtain Image of Second Engine**							
92	Switch to Rate Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
93	Switch to Day TV	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
94	Zoom out to Global View	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
95	Confirm that Pilot has Global View	0:00:03.06	0:00:01.53 Norm	1.0	4.9	3.7	1.0	SO
96	Zoom in on Engine	0:0:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
12.3	**Determine Status of Second Engine**							
97	Switch to Spotter Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
98	Switch to IR	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
99	Report Status of Engine to MFO	0:00:05.17	0:00:02.59 Norm	4.0	0	4.6	1.0	SO
100	Switch to Rate Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
101	Switch to Day TV	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO

102	Zoom out to Global View	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
13.0	**Locate Proper Target**							
13.1	**Determine Next Target**							
103	Consult Target DEC	00:00:04.03	00:00:02.02 Gama	5.9	0	3.7	4.6	SO
13.2	**Locate Commercial Plane 3**							
104	Attend to HUD	0:00:00.50	0:00:00.25 Gama	1.0	0	0	1.0	SO
105	Confirm that Pilot has Global View	0:00:03.06	0:0:01.53 Norm	1.0	4.9	3.7	1.0	SO
106	Perform Target Search	0:00:30.00	0:00:15.00 Norm	7.0	0	6.8	7.0	SO
107	Zoom in on target	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
14.0	**Prosecute Target According to Mission Reqts**							
14.1	**Determine Status of First Engine**							
108	Switch to Spotter Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
109	Switch to IR	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
110	Report Status of Engine to MFO	0:00:05.17	0:00:02.59 Norm	4.0	0	4.6	1.0	SO
14.2	**Obtain Image of Second Engine**							
111	Switch to Rate Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
112	Switch to Day TV	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
113	Zoom out to Global View	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
114	Confirm that Pilot has Global View	0:00:03.06	0:00:01.53 Norm	1.0	4.9	3.7	1.0	SO
115	Zoom in on Engine	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
14.3	**Determine Status of Second Engine**							
116	Switch to Spotter Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
117	Switch to IR	0:00:00.50	0:00:00.25	0	0	1.0	2.2	SO

			Norm					
118	Report Status of Engine to MFO	0:00:05.17	0:00:02.59 Norm	4.0	0	4.6	1.0	SO
119	Switch to Rate Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
120	Switch to Day TV	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
14.4	**Obtain Image of Third Engine**							
121	Zoom out to Global View	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
122	Confirm that Pilot has Global View	0:00:03.06	0:00:01.52 Norm	1.0	4.9	3.7	1.0	SO
123	Zoom in on Engine	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
14.5	**Determine Status of Third Engine**							
124	Switch to Spotter Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
125	Switch to IR	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
126	Report Status of Engine to MFO	0:00:05.17	0:00:02.59 Norm	4.0	0	4.6	1.0	SO
127	Switch to Rate Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
128	Switch to Day TV	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
14.6	**Obtain Image of Fourth Engine**							
129	Zoom out to Global View	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
130	Confirm that Pilot has Global View	0:00:03.06	0:00:01.53 Norm	1.0	4.9	3.7	1.0	SO
131	Zoom in on Engine	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
14.7	**Determine Status of Fourth Engine**							
132	Switch to Spotter Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
133	Switch to IR	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
134	Report Status of Engine	0:00:05.17	0:00:02.59 Norm	4.0	0	4.6	1.0	SO

135	Switch to Rate Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
136	Switch to Day TV	0:00:00.25	0:00:00.25 Norm	0	0	1.0	2.2	SO
137	Zoom out to Global View	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
15.0	**Locate Proper Target**							
15.1	**Determine Next Target**							
138	Consult Target DEC	0:00:04.03	0:00:02.02	5.9	0	3.7	4.6	SO
15.2	**Locate Commercial Plane 4**							
139	Attend to HUD	0:00:00.50	0:00:00.25 Gama	1.0	0	0	1.0	SO
140	Confirm that Pilot has Global View	0:00:03.06	0:00:01.53 Norm	1.0	4.9	3.7	1.0	SO
141	Perform Target Search	0:00:30.00	0:00:15.00 Norm	7.0	0	6.8	7.0	SO
142	Zoom in on Target	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
16.0	**Prosecute Target According to Mission Reqts**							
16.1	**Determine Status of First Engine**							
143	Switch to Spotter Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
144	Switch to IR	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
145	Report Status of Engine to MFO	0:00:05.17	0:00:02.59 Norm	4.0	0	4.6	1.0	SO
16.2	**Obtain Image of Second Engine**							
146	Switch to Rate Mode	0:00:00:50	0:00:00.25 Norm	0	0	1.0	2.2	SO
147	Switch to Day TV	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
148	Zoom out to Global View	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
149	Confirm that Pilot has Global View	0:00:03.06	0:00:01.53 Norm	1.0	4.9	3.7	1.0	SO
150	Zoom in on Engine	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO

16.3	**Determine Status of Second Engine**							
151	Switch to Spotter Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
152	Switch to IR	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
153	Report Status of Engine to MFO	0:00:05.17	0:00:02.59 Norm	4.0	0	4.6	1.0	SO
154	Switch to Rate Mode	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
155	Switch to Day TV	0:00:00.50	0:00:00.25 Norm	0	0	1.0	2.2	SO
156	Zoom out to Global View	0:00:01.00	0:00:00.50 Gama	3.7	0	1.0	5.8	SO
17.0	**Obtain Comprehensive view of Target area**							
17.1	**Determine Next Target**							
157	Consult Target DEC	0:00:04.03	0:00:02.02 Gama	5.9	0	3.7	4.6	SO
17.2	**Position Craft for Prosecution**							
158	Attend to HUD	0:00:00.50	0:00:00.25 Gama	1.0	0	0	2.2	MFO
159	Communicate with Pilot	0:00:10.00	0:00:05.00 Norm	4.0	4.9	5.3	1.0	MFO
17.3	**Employ SAR**							
160	Activate SAR	0:00:02.00	0:00:01.50 Gama	5.0	0	0	2.2	MFO
161	Take various pictures	0:00:30.00	0:00:15.00 Norm	7.0	0	6.8	5.8	MFO
18.0	**Perform Surveillance**							
18.1	**Determine Next Target**							
162	Consult Target DEC	0:00:04.03	0:00:02.02 Gama	5.9	0	3.7	4.6	SO
18.2	**Monitor Target Area**							
163	Watch for Pop up Threats							
164	Check that no soldiers are left	0:00:40.10	0:00:20.05 Norm	7.0	0	6.8	5.8	SO
165	Check that no suspicious objects left	0:02:00.00	0:01:00.00 Norm	7.0	0	6.8	5.8	SO

166	Confirm that airport operations returning to normal	0:01:00.00	0:00:30.00 Norm	7.0	0	6.8	5.8	SO
167	Begin assisting in return flight	0:00:01.00	0:00:00:00 Norm	0	0	0	0	SO
19.0	**Monitor Enemy Plane During Take-off**							
168	Monitor 1	0:01:00.00	0:00:00.00 Norm	0	0	0	0	SO
169	Monitor 2	0:01:00.00	0:00:00.00 Norm	0	0	0	0	SO
170	Monitor 3	0:01:00.00	0:00:00.00 Norm	0	0	0	0	SO

Total Tasks	186
Actual Tasks	170
Dummy Tasks	16

APPENDIX C. TIME STANDARD LOGIC

Notes. Analysis: UAV SO; Mission: Sensor Operator – stand alone

Key:

Micromodels: refers to values contained in CART and OMT explanation of how they were implemented

Other: refers to a variable created by the OMT

Repeat: Indicates an identical task (may have a different name) that copied previous values with no use of a micromodel.

Task 1: Attend to Tracker Display
- Micromodels
  - Head movement
  - Eye fixation

Task 2: Set Cursor
- Micromodels
  - Cursor movement (640px/320px)
  - Push button or toggle
  - Motor
  - Eye movement to target
  - Head movement (dist: 7.5, size: 5.0)
- Other
  - OMT second for accuracy

Task 3: Execute Lat Button Presses
- Micromodels
  - Single key finger rate X 8 button presses

Task 4: Press Tab
- Micromodels
  - Push button or toggle
  - Head movement (dist: 5.0, size:3.0)

Task 5: Execute Long Button Presses
- Repeat
  - Execute Lat Button Presses

Task 6: Press Enter
- Repeat
  - Pres Tab

Task 7: Attend to HUD
- Repeat
  - Attend to Tracker Display

Task 8: Consult Target DEC
- Micromodels
  - Head movement X 2 (there and back)
  - Eye movement X 2 (to target DEC and to HUD)
  - Hand movement (dist: 30, size:10) reaching for DEC
  - Eye fixation X 2 per page X 2 pages (4)
  - Decision process
  - Hand movement (dist: 36, size:15) returning from DEC
- Other

- OMT second for accuracy
- Page turn (.8sec)

Task 9: Compare to Image on HUD

- Micromodels
  - Eye movement
  - Head movement
  - Search time (fixations: 2, movement time: .5, fixation time: .5)
  - Perceptual process
  - Decision process

Task 10: Decide if Correct Target is in view for Prosecution

- Other
  - Zero time task

Task 11: Switch to Rate Mode

- Micromodels
  - Push button or toggle
  - Motor Process

Task 12: Count Soldiers visible in HUD Image

- Micromodels
  - Search time (fixations: 50, movement time: .1, fixations time: .3)

Task 13: Confer with MFO

- Micromodels
  - Speech: 7 words X 2 for listening to response

Task 14: Decide if further Perspective(s) is needed

- Other
  - Zero time task

Task 15: Zoom out to Global View

- Other
  - Random (1sec)

Task 16: Give Directions (to pilot)

- Micromodels
  - Speech: 25 words

Task 17: Respond to Feedback (from pilot)

- Micromodels
  - Speech: 25 words

Task 18: Adjust Controls

- Other
  - Random (3min)

Task 19: Continue Counting Soldiers

- Repeat
  - Count Soldiers visible in HUD Image

Task 20: Decide if all that have been counted are confirmed

- Other
  - Zero time task

Task 21: Zoom out to Global View

- Repeat
  - Zoom out to Global View

Task 22: Consult Target DEC

- Repeat
  - Consult Target DEC

Task 23: Attend to HUD

- Repeat
  - Attend to HUD

Task 24: Confirm that Pilot has Global View

- Micromodels
  - Speech: 8words
  - Head movement
  - Eye movement

Task 25: Perform Target Search

- Other
  - Random (30sec)

Task 26: Set Track Gate on Target

- Repeat
  - Set Cursor

Task 27: Press Joystick Trigger to Second Detent

- Micromodels
  - Button Press

Task 28: Zoom in and out as necessary

- Other
  - Random (2sec, longer than just zoom in/out)

Task 29: Confer with MFO

- Repeat
  - Confer with MFO

Task 30: Release Track Mode via Joystick Trigger

- Repeat
  - Press Joystick Trigger to Second Detent

Task 31: Zoom out to Global View

Task 32: Consult Target DEC

Task 33: Attend to HUD

Task 34: Confirm that Pilot has Global View

- Repeat
  - Confirm that Pilot has Global View

Task 35: Perform Target Search

- Repeat:
  - Perform Target Search

Task 36: Zoom in out Target Area

- Repeat
  - Zoom out to Global View

Task 37: Confer with MFO about Activity

- Repeat
  - Confer with MFO

Task 38: Manipulate Camera as necessary

- Micromodels
  - Decision process
- Other
  - Random (15sec)

Task 39: Decide if Further Perspective(s) is needed

- Other
  - Zero time task

Task 40: Give Information (to MFO)

- Micromodels
  - Speech: 25words
  - Decision process X 5 to represent scanning and thinking about what is seen

Task 41: Receive Feedback (from MFO)
- Micromodels
  - Listening: 25words

Task 42: Adjust Controls
- Repeat
  - Adjust Controls

Task 43: Give Directions
- Repeat
  - Give Directions

Task 44: Respond to Feedback
- Repeat
  - Give Directions

Task 45: Zoom out to Global View
Task 46: Consult Target DEC
Task 47: Attend to HUD
Task 48: Confirm that Pilot has Global View
Task 49: Perform Target Search
Task 50: Zoom in on Starboard Engine
- Repeat
  - Zoom in on target area

Task 51: Switch to Spotter Mode
- Repeat
  - Switch to Rate Mode

Task 52: Switch to IR
- Repeat
  - Switch to Rate Mode

Task 53: Report Status of Engine to MFO
- Micromodels
  - Speech: 15words

Task 54: Switch to Rate Mode
- Repeat
  - Switch to Rate Mode

Task 55: Switch to Day TV
- Repeat
  - Switch to Rate Mode

Task 56: Zoom out to Global View
Task 57: Confirm that Pilot has Global View
Task 58: Zoom in on Port Engine
- Repeat
  - Zoom in on Starboard Engine

Task 59: Switch to Spotter Mode
Task 60: Switch to IR
Task 61: Report Status of Engine to MFO
- Repeat
  - Report Status of Engine to MFO

Task 62: Switch to Rate Mode
Task 63: Switch to Day TV
Task 64: Zoom out to Global View
Task 65: Consult Target DEC
Task 66: Attend to HUD
Task 67: Confirm that Pilot has Global View
Task 68: Perform Target Search
Task 69: Zoom in on Target
Task 70: Switch to Spotter Mode
Task 71: Switch IR

Task 72: Report Status of Engine to MFO

- Repeat
  - Report Status of Engine to MFO

Task 73: Switch to Rate Mode
Task 74: Switch to Day TV
Task 75: Zoom out to Global View
Task 76: Confirm that Pilot has Global View
Task 77: Zoom in on Engine

- Repeat
  - Zoom in on Target

Task 78: Switch to Spotter Mode
Task 79: Switch to IR
Task 80: Report status of Engine to MFO

- Repeat
  - Report status of Engine to MFO

Task 81: Switch to Rate Mode
Task 82: Switch to Day TV
Task 83: Zoom out to Global View
Task 84: Consult Target DEC
Task 85: Attend to HUD
Task 86: Confirm that Pilot has Global View
Task 87: Perform Target Search
Task 88: Zoom in on target
Task 89: Switch to Spotter Mode
Task 90: Switch to IR
Task 91: Report Status of Engine to MFO
Task 92: Switch to Rate Mode
Task 93: Switch to Day TV
Task 94: Zoom out to Global View
Task 95: Confirm that Pilot has Global View
Task 96: Zoom in on Engine
Task 97: Switch to Spotter Mode
Task 98: Switch to IR
Task 99: Report Status of Second Engine to MFO
Task 100: Switch to Rate Mode
Task 101: Switch to Day TV
Task 102: Zoom out to Global View
Task 103: Consult Target DEC
Task 104: Attend to HUD
Task 105: Confirm that Pilot has Global View
Task 106: Perform Target Search
Task 107: Zoom in on Target
Task 108: Switch to Spotter Mode
Task 109: Switch to IR
Task 110: Report Status of Engine to MFO
Task 111: Switch to Rate Mode
Task 112: Switch to Day TV
Task 113: Zoom out to Global View
Task 114: Confirm that Pilot has Global View
Task 115: Zoom in on Second Engine
Task 116: Switch to Spotter Mode
Task 117: Switch to IR
Task 118: Report Status of Engine to MFO
Task 119: Switch to Rate Mode
Task 120: Switch to Day TV
Task 121: Zoom out to Global View

Task 122: Confirm that Pilot has Global View
Task 123: Zoom in on Engine

- Repeat
  - Zoom in on Second Engine

Task 124: Switch to Spotter Mode
Task 125: Switch to IR
Task 126: Report Status of Engine to MFO

- Repeat
  - Report Status of Second Engine to MFO

Task 127: Switch to Rate Mode
Task 128: Switch to Day TV
Task 129: Zoom out to Global View
Task 130: Confirm that Pilot has Global View
Task 131: Zoom in on Engine

- Repeat
  - Zoom in on Third Engine

Task 132: Switch to Spotter Mode
Task 133: Switch to IR
Task 134: Report Status of Engine

- Repeat
  - Report Status of Third Engine to MFO

Task 135: Switch to Rate Mode
Task 136: Switch to Day TV
Task 137: Zoom out to Global View
Task 138: Consult Target DEC
Task 139: Attend to HUD
Task 140: Confirm that Pilot has Global View
Task 141: Perform Target Search
Task 142: Zoom in on Target
Task 143: Switch to Spotter Mode
Task 144: Switch to IR
Task 145: Report Status of Engine to MFO
Task 146: Switch to Rate Mode
Task 147: Switch to Day TV
Task 148: Zoom out to Global View
Task 149: Confirm that Pilot has Global View
Task 150: Zoom in on Engine
Task 151: Switch to Spotter Mode
Task 152: Switch to IR
Task 153: Report Status of Second Engine to MFO
Task 154: Switch to Rate Mode
Task 155: Switch to Day TV
Task 156: Zoom out to Global View
Task 157: Consult Target DEC
Task 158: Attend to HUD
Task 159: Communicate with Pilot

- Other
  - Random (10 sec)

Task 160: Activate SAR

- Other
  - Random (2 Sec)

Task 161: Take Various Pictures

- Other
  - Random (30 Sec)

Task 162: Consult Target DEC

Task 163: Watch for Pop-up Threats

- Other
  - Zero time continuous task

Task 164: Check that no Soldiers are left

- Other
  - Random (40.1sec)

Task 165: Check that no Suspicious left

- Other
  - Random (2mins)

Task 166: Confirm that airport operations are returning to normal

- Other
  - Random (1min)

Task 167: Begin assisting in return flight

- Other
  - Random (1sec)

Task 168: Monitor 1

- Other
  - Random (1 min)

Task 169: Monitor 2

- Repeat
  - Monitor 1

Task 170: Monitor 3

- Repeat
  - Monitor 1

APPENDIX D. McCracken & Aldrich Description of VACP Workload

Table D-1.

Descriptions of Workload Levels by Category

Visual Activity

Value	Description
0.0	No Visual Activity
1.0	Visually Register/Detect (i.e., detect image)
3.7	Visually Discriminate (i.e., detect visual differences)
4.0	Visually Inspect/Check (i.e., static inspection)
5.0	Visually Locate/Align (i.e., selective orientation)
5.4	Visually Track/Follow (i.e., maintain orientation)
5.9	Visually Read (i.e., symbol)
7.0	Visually Scan/Search/Monitor (i.e., continuous)

Auditory Activity

Value	Description
0.0	No Auditory Activity
1.0	Detect/Register Sound
2.0	Orient to Sound (i.e., general orientation)
4.2	Orient to Sound (i.e., selective orientation)
4.3	Verify Auditory Feedback
4.9	Interpret Semantic Content (i.e., speech)
6.6	Discriminate Sound Characteristics
7.0	Interpret Sound Patterns (e.g., pulse rate)

Cognitive Activity

Value	Description
0.0	No Cognitive Activity
1.0	Automatic (i.e., simple association)
1.2	Alternative Selection
3.7	Sign/Signal Recognition
4.6	Evaluation/Judgment (i.e., consider a single aspect)
5.3	Encoding/Decoding, Recall
6.8	Evaluation/Judgment (i.e., consider several aspects)
7.0	Estimation, Calculation, Conversion

Psychomotor Activity

Value	Description
0.0	No Psychomotor Activity
1.0	Speech
2.2	Discrete Actuation (i.e., button, toggle, trigger)
2.6	Continuous Adjustment (i.e., flight or sensor control)

4.6	Manipulative
5.8	Discrete Adjustment (i.e., rotary, thumbwheel, lever)
6.5	Symbolic Production (i.e., writing)
7.0	Serial Discrete Manipulation (i.e., keyboard entries)

Table D-2. Categories of Tasks for which Time Estimates can be Calculated

Cognitive/ Perceptual:

Eye Fixation Time
Eye Movement Time (target located at eye level)
Decision Process
Listening Rate
Mental Rotation (visualization)
Perceptual Process
Prioritization
Reading Rate
Response Time (RT) Measures:
- Choice RT
- Simple RT: On or Off Response
- Simple RT: Physical Match
- Simple RT: Name Match
- Simple RT: Category Match

Search Time
Terrain Association (in map reading)

Psychomotor:

Cursor Movement with Trackball, Positioning Time
Cursor Movement with Mouse
Cursor Movement with Step Keys
Cursor Movement using Text Keys
Hand Movement (Fitt's Law – Welford variant)
Head Movement Time (target located at head level)
Motor Process
Pushbutton or Toggle Switch
Rotary Dial
Single Finger Keying Rate
Speech
Typing Rate
Walking Rate

APPENDIX E. WORKLOAD LOGIC

Notes. Analysis: UAV SO; Mission: Sensor Operator – stand alone

Task 1: Attend to Tracker Display

V: (1.0) SO looks up at the tracker to start completing tasks
A: 0
C: 0
P: (1.0) Minimal head movement may be involved

Task 2: Set Cursor
V: (5.0) SO monitors discrete movements of the cursor
A: 0
C: 0
P: (2.2) SO manipulates a track ball to adjust the cursor

Task 3: Execute Lat Button Presses
V: (5.9) Involves reading the coordinates and visually locating the correct keys
A: 0
C: (1.0) SO must confirm correct key presses
P: (7.0) SO enters the coordinates on the keyboard

Task 4: Press Tab
V: (5.9) SO has visually locates the Tab key
A: 0
C: (1.0) SO must distinguish the Tab key - an automatic association
P: (2.2) SO presses a button

Task 5: Execute Long Button Presses
V: (5.9) Involves reading the coordinates and visually locating the correct keys
A: 0
C: (1.0) SO must confirm correct key presses
P: (7.0) SO enters the coordinates on the keyboard

Task 6: Press Enter
V: (5.9) SO has visually locates the Enter key
A: 0
C: (1.0) SO must distinguish the Enter key - an automatic association
P: (2.2) SO presses a button

Task 7: Attend to HUD
V: (1.0) SO looks up at the tracker to start completing tasks
A: 0
C: 0
P: (1.0) Minimal head movement may be involved

Task 8: Consult Target DEC
V: (5.9) SO reads target info
A: 0
C: (3.7) SO must recognize/comprehend the target information
P: (4.6) SO turns pages

Task 9: Compare to image on HUD
V: (4.0) SO looks at static picture/looks at live picture
A: 0
C: (6.8) SO compares several aspects of target information to the target in view
P: (1.0) Head movement is involved

Task 10: Decide if Correct Target is in view for Prosecution
V: 0
A: 0
C: (7.0) This task requires decision making level of cognition
P: 0

Task 11: Switch to Rate Mode
V: 0
A: 0
C: (1.0) SO must distinguish between the switch and the desired mode
P: (2.2) SO toggles switch

Task 12: Count Soldiers Visible in the HUD image
V: (7.0) SO scans the HUD
A: 0
C: (6.8) SO must distinguish targets from non-targets
P: (5.8) SO points at the soldiers on the HUD (physical tracking)

Task 13: Confer with MFO
V: (4.0) SO obtains information from the HUD
A: (4.9) SO listens to MFO
C: (5.3) Compromise between 4.6 and 5.8
P: (1.0) Speaking

Task 14: Decide if other perspectives are needed.
V: 0
A: 0
C: (6.8) SO considers several aspects in making a decision
P: 0

Task 15: Zoom out to Global view
V: (3.7) SO monitors HUD
A: 0
C: (1.0) Automatic association of zoom direction on screen and intended zoom
P: (5.8) SO manipulates throttle

Task 16: Give Directions
V: (5.0) SO obtains information from the HUD
A: 0
C: (6.8) SO translates the visual image into directions
P: (1.0) Speaking

Task 17: Respond to Feedback
V: 0
A: (4.9) SO holds dialogue with AVO
C: (5.3) Compromise between 4.6 and 5.8
P: (1.0) Speaking.

Task 18: Adjust Controls
V: (5.4) SO maintains orientation
A: 0
C: (6.8) SO manually controls turret/cameras
P: (7.0) Controlling turret/cameras involves several discrete movements

Task 19: Continue Counting Soldiers
V: (7.0) SO scans the HUD
A: 0
C: (6.8) SO must distinguish targets from non-targets
P: (5.8) SO points at the soldiers on the HUD (physical tracking)

Task 20: Decide if all the all that can be Counted are Confirmed
V: 0
A: 0
C: (6.8) Decision making
P: 0

Task 21: Zoom out to Global View
Repeat: Zoom out to Global View

Task 22: Consult Target DEC
Repeat: Consult Target DEC

Task 23: Attend to HUD
Repeat: Attend to HUD

Task 24: Confirm that pilot has Global View
V: 1.0 **Gap in logic**
A: 4.9
C: 3.7
P: 1.0

Task 25: Perform Target Search
V: (7.0) **Gap in logic**
A: 0
C: (6.8)
P: (7.0)

Task 26: Set Track Gate on Target
V: (5.0) SO tracks a cursor on the target
A: 0
C: 0
P: (2.2) SO manipulates a track ball to adjust the cursor

Task 27: Press Joystick Trigger to Second Detent
V: 0
A: 0
C: 0
P: (2.2) SO presses trigger

Task 28: Zoom in and out as necessary
V: (5.0) **Gap in logic**
A: 0
C: (3.7)
P: (5.8)

Task 29: Confer with MFO
Repeat: Confer with MFO

Task 30: Release Track Mode via Joystick Trigger
Repeat: Press Joystick Trigger to Second Detent

Task 31: Zoom out to Global View
Task 32: Consult Target DEC
Task 33: Attend to HUD
Task 34: Confirm that Pilot has Global View
Repeat: Confirm that Pilot has Global View

Task 35: Perform Target Search
Repeat: Perform Target Search

Task 36: Zoom in on Target Area
Repeat: Zoom out to Global View

Task 37: Confer with MFO about Activity

Task 38: Manipulate Camera as Necessary
Repeat: Zoom in and out as Necessary

Task 39: Decide if further Perspective(s) is needed
Repeat: Decide if all that can be counted are confirmed

Task 40: Give Information
Repeat: Give Directions

Task 41: Receive Feedback
V: 0
A: (4.9) SO listens to AVO
C: (5.3) Compromise between 4.6 and 5.8
P: 0

Task 42: Adjust Controls
Repeat: Adjust Controls

Task 43: Give Directions
Repeat: Give Information

Task 44: Respond to Feedback
V: 0
A: (4.9) SO listens to AVO
C: (5.3) Compromise between 4.6 and 5.8
P: (1.0) Speaking

Task 45: Zoom out to Global View
Task 46: Consult Target DEC

Task 47: Attend to HUD
Task 48: Confirm that Pilot has Global View
Task 49: Perform Target Search
Task 50: Zoom in on Starboard Engine
Repeat: Zoom in out Target Area

Task 51: Switch to Spotter Mode
Repeat: Switch to Rate Mode

Task 52: Switch to IR
Repeat: Switch to Rate Mode

Task 53: Report Status of Engine to MFO
V: (4.0) **Gap in logic**
A: 0
C: (4.6)
P: (1.0)
Task 54: Switch to Rate Mode
Task 55: Switch to Day TV
Task 56: Zoom out to Global View
Task 57: Confirm that Pilot has Global View
Task 58: Zoom in on Port Engine
Repeat: Zoom in on Starboard Engine

Task 59: Switch to Spotter Mode
Task 60: Switch to IR
Task 61: Report Status of Engine to MFO
Repeat: Report Status of Engine to MFO

Task 62: Switch to Rate Mode
Task 63: Switch to Day TV
Task 64: Zoom out to Global View
Task 65: Consult Target DEC
Task 66: Attend to HUD
Task 67: Confirm that Pilot has Global View
Task 68: Perform Target Search
Task 69: Zoom in on Target
Repeat: Zoom out to Global View

Task 70: Switch to Spotter Mode
Task 71: Switch to IR
Task 72: Report Status of Engine to MFO
Task 73: Switch to Rate Mode
Task 74: Switch to Day TV
Task 75: Zoom out to Global View
Task 76: Confirm that Pilot has Global View
Task 77: Zoom in on Engine
Repeat: Zoom in on Target

Task 78: Switch to Spotter Mode
Task 79: Switch to IR
Task 80: Report Status of Engine to MFO
Repeat: Report Status of Engine to MFO

Task 81: Switch to Rate Mode
Task 82: Switch to Day TV

Task 83: Zoom out to Global View
Task 84: Consult Target DEC
Task 85: Attend to HUD
Task 86: Confirm that Pilot has Global View
Task 87: Perform Target Search
Task 88: Zoom in on Target
Task 89: Switch to Spotter Mode
Task 90: Switch to IR
Task 91: Report Status of Engine to MFO
Task 92: Switch to Rate Mode
Task 93: Switch to Day TV
Task 94: Zoom out to Global View
Task 95: Confirm that Pilot has Global View
Task 96: Zoom in on Second Engine
Task 97: Switch to Spotter Mode
Task 98: Switch to IR
Task 99: Report Status of Engine to MFO
Task 100: Switch to Rate Mode
Task 101: Switch to Day TV
Task 102: Zoom out to Global View
Task 103: Consult Target DEC
Task 104: Attend to HUD
Task 105: Confirm that Pilot has Global View
Task 106: Perform Target Search
Task 107: Zoom in on Target
Task 108: Switch to Spotter Mode
Task 109: Switch to IR
Task 110: Report Status of Engine to MFO
Task 111: Switch to Rate Mode
Task 112: Switch to Day TV
Task 113: Zoom out to Global View
Task 114: Confirm that Pilot has Global View
Task 115: Zoom in on Engine
Task 116: Switch to Spotter Mode
Task 117: Switch to IR
Task 118: Report Status of Engine to MFO
Task 119: Switch to Rate Mode
Task 120: Switch to Day TV
Task 121: Zoom out to Global View
Task 122: Confirm that Pilot has Global View
Task 123: Zoom in on Engine
Repeat: Zoom in on Second Engine

Task 124: Switch to Spotter Mode
Task 125: Switch to IR
Task 126: Report Status of Engine to MFO
Repeat: Report Status of Second Engine to MFO

Task 127: Switch to Rate Mode
Task 128: Switch to Day TV
Task 129: Zoom out to Global View
Task 130: Confirm that Pilot has Global View
Task 131: Zoom in on Engine
Repeat: Zoom in on Second Engine

Task 132: Switch to Spotter Mode

Task 133: Switch to IR
Task 134: Report Status of Engine to MFO
Repeat: Report Status of Second Engine to MFO

Task 135: Switch to Rate Mode
Task 136: Switch to Day TV
Task 137: Zoom out to Global View
Task 138: Consult Target DEC
Task 139: Attend to HUD
Task 140: Conform that Pilot has Global View
Task 141: Perform Target Search
Task 142: Zoom in on Target
Task 143: Switch to Spotter Mode
Task 144: Switch to IR
Task 145: Report Status of Engine to MFO
Task 146: Switch to Rate Mode
Task 147: Switch to Day TV
Task 148: Zoom out to Global View
Task 149: Confirm that Pilot has Global View
Task 150: Zoom in on Engine
Task 151: Switch to Spotter Mode
Task 152: Switch to IR
Task 153: Report Status of Engine to MFO
Task 154: Switch to Rate Mode
Task 155: Switch to Day TV
Task 156: Zoom out to Global View
Task 157: Consult Target DEC
Task 158: Attend to HUD
Task 159: Communicate with Pilot
Repeat: Confer with MFO

Task 160: Activate SAR
Repeat: Set Cursor

Task 161: Take Various Pictures
Repeat: Check that no soldiers left (future task)

Task 162: Consult Target DEC
Task 163: Watch for Pop-up Threats
Not yet defined

Task 164: Check that no Soldiers are left
Repeat: Count Soldiers Visible in HUD Image

Task 165: Check that no Suspicious Objects left
Repeat: Count Soldiers Visible in HUD Image
Task 166: Confirm that Airport Operations returning to Normal
Repeat: Count Soldiers Visible in HUD Image

Task 167: Begin Assisting in Return flight
Task only represents a next-step, no true task execution
V: 0
A: 0
C: 0
P: 0

Task 168: Monitor 1
V: 0
A: 0
C: 0
P: 0

Task 169: Monitor 2
V: 0
A: 0
C: 0
P: 0

Task 170: Monitor 3
V: 0
A: 0
C: 0
P: 0

APPENDIX F. VARIABLE CATALOGUE

Notes. Analysis: UAV SO; Mission: Sensor Operator – stand alone

Name	Description	Type	External
GiveDirect	Used for rejoining multiple paths. True status allows a Dummy to release. [2.2.1 t1,t3]. Initialized in preceding Dummy task..	Integer	False
GiveInfo	Used for rejoining multiple paths. True status allows a Dummy to release. [6.2.1 t2,t6]. Initialized in preceding Dummy task.	Integer	False
RecFeedback	Used for rejoining multiple paths. True status allows a Dummy to release. [6.2.1 t3,t6]. Initialized in preceding Dummy task.	Integer	False
RespFeedback	Used for rejoining multiple paths. True status allows a Dummy to release. [2.2.1 t2,t3]. Initialized in preceding Dummy task.	Integer	False
AdjustCont	Used for rejoining multiple paths. True status allows a Dummy to release. [2.2.2 t1,t5]. Initialized in preceding Dummy task.	Integer	False
CountDone	Used for rejoining multiple paths. True status allows a Dummy to release. [2.2.2 t2,t5]	Integer	False
AdjCont	Used for rejoining multiple paths. True status allows a Dummy to release. [6.2.1 t4,t6]. Initialized in preceding Dummy task.	Integer	False
FlowA	Used for rejoining multiple paths of upper-level functions. True status allows a Dummy to release. [2.2.1 t3, 2.2 t1]	Integer	False
FlowB	Used for rejoining multiple paths of upper-level functions. True status allows a Dummy to release. [2.2.2 t4, 2.2 t1]	Integer	False
ResFeedback	Used for rejoining multiple paths. True status allows a Dummy to release. [6.2.2 t2,t7]. Initialized in preceding Dummy task.	Integer	False
Directions	Used for rejoining multiple paths. True status allows a Dummy to release. [6.2.2 t3,t7]. Initialized in preceding Dummy task.	Integer	False
FlowC	Used for rejoining multiple paths of upper-level functions. True status allows a Dummy to release. [6.2.1t6, 6.2 t1]	Integer	False
FlowD	Used for rejoining multiple paths of upper-level functions. True status allows a Dummy to release. [6.2.2 t3, 6.2 t1]	Integer	False
True	Initializes True [t1]	Integer	False
False	Initializes False [t1]	Integer	False
Monitor	Initializes as True in ending effect of Dummy executed as an external event, True status activates new goal state; False status ends goal state. [t2, 19.0 t1]	Integer	False
Mission	Used to control time of task 18.2 t1 to last as long as t2-5. [18.1 t1, 18.2 t1, t5].	Integer	False